Journal
of
The Franklin Institute
Devoted to Science and the Mechanic Arts

Vol. 217 JUNE, 1934 No. 6

LATE DEVELOPMENTS IN MICROSCOPY.*

BY

FRANCIS F. LUCAS, D.Sc.,

Bell Telephone Laboratories.

INTRODUCTION.

Ten years ago I addressed The Franklin Institute on the subject, "High Power Metallography—Some Recent Developments in Photomicrography and Metallurgical Research." I am honored by a second invitation to speak on "Late Developments in Microscopy."

In my former paper, methods for improving resolution were discussed and the statement was made that further improvements in resolution would be obtained by the use of higher aperture objectives or by decreasing the wave length of the light used. It is of these developments that I wish to speak tonight.

At the time of my first appearance before the Institute, we had commissioned the Zeiss Works of Jena to construct an ultra-violet microscope and also to revive the monobrom-naphthalene objective, a system which has the utmost resolving power for visible light. The ultra-violet microscope has about twice the theoretical resolving power of the best system employing visible light.

These equipments were delivered in 1925. The ultra-violet microscope designed by us for metallography has not proved an outstanding success as yet in that branch of science but has written a new chapter in the tools available for biological research.

* Presented at a meeting held Thursday, February 15, 1934.

The high aperture mono-brom-naphthalene lens is now, after nearly ten years of experimental work, just beginning to yield results in the science of metallography.

Before the advantages of this very high aperture lens could be realized in practice, other developments were needed. It was necessary to develop better and more uniform abrasives; to learn how better to prepare specimens for microscopic examination and a new precision type metallographic apparatus was required.

The ultra-violet microscope was developed in 1900 for biological research. It had a very brief existence. Soon it passed into the realm of scientific obscurity, apparently an instrument too complicated to be of any use. It remained practically unused for nearly a quarter of a century and was then redesigned as a metallurgical microscope. Its mysteries of operation were solved; its latent powers discovered and set to work, not in the science of metallography but in the study of living things.

As a metallurgical instrument its use was limited because most metallurgical specimens absorb ultra-violet light so strongly that little of the light is reflected. One may perhaps wonder why investigations in the biological sciences should appear from an industrial research laboratory. It comes about through the fact that tools and technique developed for doing an industrial job have proved of great interest to biologists.

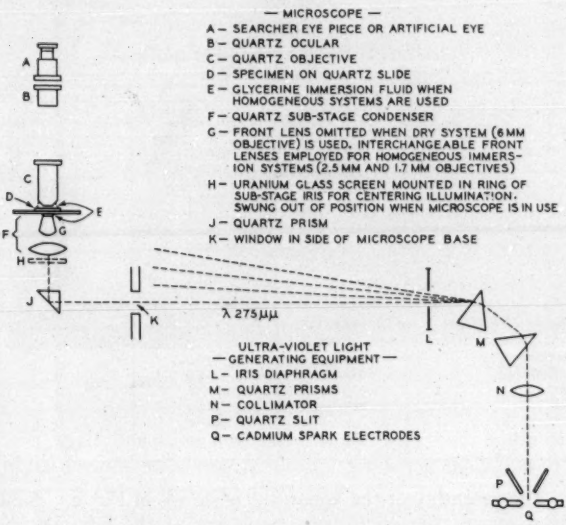
One might speculate on the thought that a given type cell which, we are taught, always reproduces cells of like type, probably has something inherent in its makeup which is different from another type cell which in turn reproduces cells of its own type. My interest and coöperation in studies of this general nature have been sought and inspired by eminent workers almost everywhere that civilized man studies and works. The methods of ultra-violet microscopy about to be described were developed as a possible means of deriving new information on problems which affect the welfare of mankind. I shall confine myself to a discussion of the methods devised and leave the cytological discussions to my associates.

Our visible spectrum, broadly speaking, lies within the range of $\lambda 7000$ to $\lambda 4000$. From $\lambda 4000$ to $\lambda 3000$ is the region

of the spectrum in which transition occurs from visible blue to the upper range of the ultra-violet. Since the absorption of ultra-violet light by air becomes very strong below λ2000, there is thus a range from about λ3000 to λ2000 which is open to exploration by microscopic means. Conceivably we might construct an instrument to operate at shorter wave lengths if required.

The ultra-violet microscope in its present state of development is confined to a single wave length of light. It may be used, as will be described later, for observing the effects on living cells and organisms of wave lengths other than the one for which it is designed.

FIG. 1.


— MICROSCOPE —
A — SEARCHER EYE PIECE OR ARTIFICIAL EYE
B — QUARTZ OCULAR
C — QUARTZ OBJECTIVE
D — SPECIMEN ON QUARTZ SLIDE
E — GLYCERINE IMMERSION FLUID WHEN HOMOGENEOUS SYSTEMS ARE USED
F — QUARTZ SUB-STAGE CONDENSER
G — FRONT LENS OMITTED WHEN DRY SYSTEM (6 MM OBJECTIVE) IS USED. INTERCHANGEABLE FRONT LENSES EMPLOYED FOR HOMOGENEOUS IMMERSION SYSTEMS (2.5 MM AND 1.7 MM OBJECTIVES)
H — URANIUM GLASS SCREEN MOUNTED IN RING OF SUB-STAGE IRIS FOR CENTERING ILLUMINATION. SWUNG OUT OF POSITION WHEN MICROSCOPE IS IN USE
J — QUARTZ PRISM
K — WINDOW IN SIDE OF MICROSCOPE BASE
λ 275 μμ
ULTRA-VIOLET LIGHT — GENERATING EQUIPMENT —
L — IRIS DIAPHRAGM
M — QUARTZ PRISMS
N — COLLIMATOR
P — QUARTZ SLIT
Q — CADMIUM SPARK ELECTRODES

Optical diagram of the ultra-violet microscope.

The optical diagram is shown in Fig. 1. The microscope parts are at the left and the light generating parts at the right. All optical parts are of quartz. The system is de-

signed to operate on wave length λ2750 (Cd 2748) for reasons presented elsewhere.[1-2] A high tension spark is generated across cadmium electrodes. The light generated by the spark is spectroscopically decomposed into the monochromatic slit images of the light source. The images are not all monochromatic, but are composite images of groups of lines which the monochromator has failed to separate as individuals. The 2750 group was chosen because it contains only a single strong line. The weaker lines of this group probably do not register. The slit images have been analyzed and their true spectroscopic nature determined.

Spectroscopic data are given in Table I. In this discussion, wave length references denote slit images for the sake of brevity.

TABLE I.

Wave Lengths Used with Ultra-Violet Microscope.

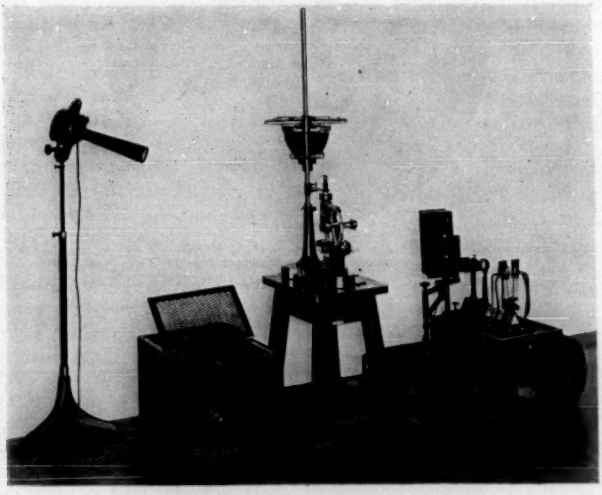
Electrode Metal.	Slit Image Wave Length Group.	Wave Lengths Comprising the Slit Image.	Spark Intensity Rating from Kayser's Tables.
Cadmium.....	2750	2707	2
		2734	2
		2748	10
		2764	3
		2775	3
Cadmium.....	2573	2552	2
		2573	10
Cadmium.....	2300	2306	3
		2312	10
		2321	7
		2329	6
Cadmium.....	2265	2265	10
		2288	10
Cadmium.....	2194	2194	4
Cadmium.....	2144	2144	6
Zinc.....	2138	2138	2
Zinc.....	2100	2100	8
		2102	6
		2104	5

The assembly of the apparatus is shown in Fig. 2. As in the diagram, the microscope parts are at the left and the spark generating apparatus at the right.

The apparatus is so aligned that the desired wave length may enter the base of the microscope through a window. It is received by a right angle prism and directed upward to

the sub-stage condenser which is focused to illuminate the specimen on the stage above. The specimen, if a living cell or organism, is mounted on a quartz slide in a suitable isotonic salt solution and covered with a quartz slip. The slip is sealed with a mixture of vaseline and olive oil.

FIG. 2.



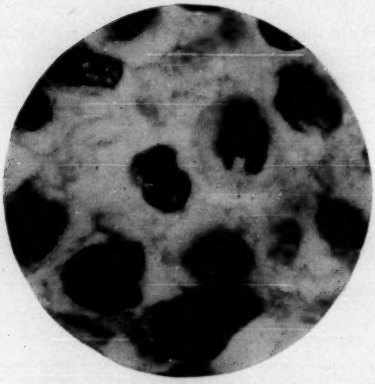
The ultra-violet microscope.

THE ULTRA-VIOLET MICROSCOPE IN BIOLOGY.

I shall illustrate our early work with this equipment which demonstrated that resolution could be greatly improved by use of the ultra-violet microscope.

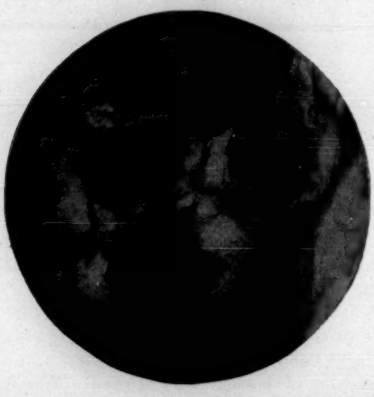
Figure 3 is a photograph of cellular structure taken with an objective of the highest order of resolving power available for visible light microscopes. The section was about 5 mu in thickness and of course was stained. We need not be concerned with cytological details but only let us establish the order of resolution and magnification obtained in good

FIG. 3.



Cellular structure photographed with an apochrochromatic objective of highest resolving power available for visible light. Magnification 1000 X.

FIG. 4.



An unstained section of the same material used for Fig. 3 but in this case photographed with the ultra-violet microscope. Resolution has been greatly increased; selective absorption is manifested, and detail above or below the focal plane has had no effect on the detail within the focal plane. Magnification 1500 X.

practice with the best equipment available for use with visible light. This photograph was taken for comparison with ultra-violet photographs of a similar but unstained section. It was found that an unstained specimen was better suited for the ultra-violet microscope than a stained one.

Figure 4 was taken with the ultra-violet microscope and is of a specimen similar to that used for the preceding illustration except that the tissue was not stained. The magnification is 1500 times instead of 1000, which was about the useful limit for this material with the visible light microscope. It is apparent that the ultra-violet microscope has greatly increased resolution. Selective absorption has contributed to make the detail visible. Detail above or below the focal plane has had no effect on the detail within the focal plane.

Improvement in resolution is not the sole achievement of which the ultra-violet microscope is capable. It has other and later accomplishments to its credit.

It has led to the development of optical sectioning; to the microscopy of living material; to the application of micro-photometry as a method of analysis to ultra-violet plates of living things; to possible methods for comparing living cells on the basis of their reaction to ultra-violet radiations, and to a study of the lethal effects of different wave lengths on cells.

OPTICAL SECTIONING OF LIVING CELLS.

Figure 5 is a diagram illustrating optical sectioning. In learning to use the equipment as a metallurgical microscope

FIG. 5.

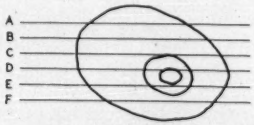


Diagram illustrating optical sectioning. A transparent specimen such as a cell itself microscopic in size may be sectioned optically. Focal planes are spaced one-quarter micron or more apart. Detail above or below the focal plane does not interfere. Successive photographs taken on planes *A*, *B*, *C*, etc., give a progressive record of the structure.

the focusing problem was solved and certain inherent possibilities of the ultra-violet system were discovered. It was

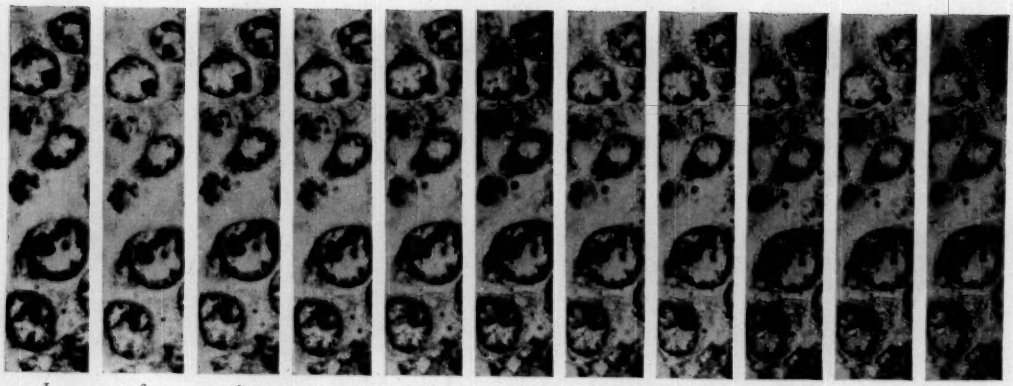
found that the plane of focus was one of inappreciable depth. Circumstances suggested that if a transparent specimen were substituted for the opaque metallurgical specimen it should be possible to photograph details of structure on a great many optical planes because detail above and below the focus would not interfere, owing to the exceedingly shallow depth of focus. This discovery led to the development of optical sectioning. Figuratively speaking, it allows us to place the microscope within a single living cell, itself microscopic in size, and to take photographs of the structure within the cell at very high magnifications, to photograph upward and downward on different planes spaced one-quarter micron or more apart.

Figure 6 shows portions of photographs from a series of optical sections. They are of fixed experimental tumor material, not stained. The photographs were taken on planes spaced 1/4 micron apart. They constitute the first practical demonstration of optical sectioning.

In the development of the photographic methods as applied to living animal cells I have collaborated principally with Dr. Mary B. Stark, who has prepared the material and evaluated and interpreted the results. To illustrate the application of the ultra-violet microscope I shall quote and show several of the illustrations from a joint paper [3] published in the *Journal of Morphology and Physiology:*

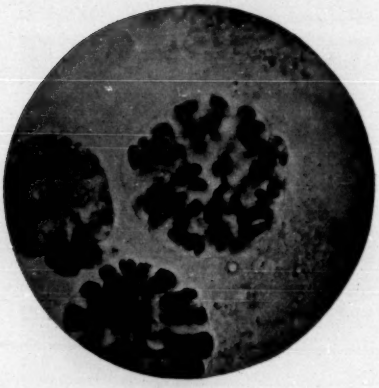
"The desire so often expressed that if one could only observe directly the exact nature of nuclear phenomena in living cells, it would be possible to follow the continuity of chromatin from one generation of cells to the next is beginning to be realized. The so-called 'optically empty' nuclei of living cells, which have time after time served as evidence that the differentiations brought out by technical methods are artifacts, when photographed with the ultra-violet light are found not to be homogeneous or optically empty, but to contain the chromatin, even though diffuse, in the form of early diatene chromosomes (Fig. 7), thus proving that chromatin, though more liquid or diffuse in some stages, is actually continuous. Photomicrographs confirm the findings of many observers on the spermatogenesis of the grasshopper—especially in the spinning out of the chromonema (Fig. 8) from the solid blocks of the diatene

FIG. 6.



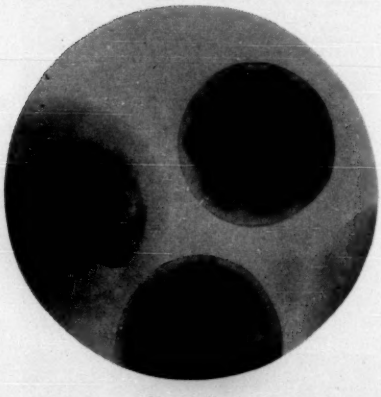
Optical sections of fixed but unstained mouse tumor specimen, photographed at a magnification of 1800 × on planes spaced one-quarter micron apart.

FIG. 7.



Living sperm cells of the grasshopper photographed with the ultra-violet microscope. Magnification 1800 ×.

FIG. 8.

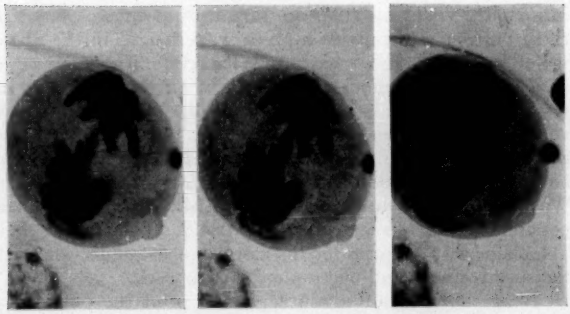


Same as Fig. 7.

stage, the pairing of the same in the leptotene stage, the development of the tetrads, the final distribution of the chromosomes in the resulting spermatids and their return to a spiral chromonema, each enclosed in its own vesicle."

Figure 9 consists of several optical sections from a sequence taken through a living cell in the process of mitotic division,

FIG. 9.



Optical sections from a sequence taken through a living cell in the process of mitotic division, namely the anaphase of secondary spermatocyte division of melanoplus femur rubrum. The magnification is 1200 × and the spacing of optical sections is one-quarter micron.

namely the anaphase of secondary spermatocyte division of melanoplus femur rubrum. The magnification is 1200 times and the spacing of optical sections is 1/4 micron.

If the specimen being photographed is a living cell, it is obvious that the image which is recorded on the photographic plate is a record not only of the structure but also of the ultra-violet light absorbed or transmitted by the cell. Considering the photographic negative, those areas which are darkest represent greatest transmission of ultra-violet light by that particular detail of the cell and those areas which are lightest represent greatest absorption in the cellular detail.

THE ADAPTATION OF MICRO-PHOTOMETRY TO ULTRA-VIOLET MICROSCOPY OF LIVING CELLS.

In spectroscopy, methods of micro-photometry are being used more and more for the purpose of analyzing the fine

detail of spectral plates. These methods translate density of the photographic image into the form of a curve the coördinates of which are density and distance. In the photographic plates secured with the ultra-violet microscope there is an extraordinary wealth of fine detail. Besides, as has been noted, varying density in these plates has a more important significance than merely differentiating structure.

The relative densities of two or more details of structure in an ultra-violet negative are measures of the responses of these particular details to a given wave length in the ultra-violet region of the spectrum. Therefore if one were to apply methods of micro-photometry to an ultra-violet plate, say of a living cell, it not only would be possible to make a very careful analysis of the detail not readily apparent to the eye but it would be possible to measure in relative terms how these minute details react to the ultra-violet radiation. We have applied these methods and have investigated the possibilities. I am indebted to Mr. A. H. Staud of Bell Telephone Laboratories for his assistance in connection with the spectroscopic and micro-photometric work.

It has been found advantageous to print the plate on a fine grain process film, and secure a transparency. The actual negative could be used but experience indicates that the transparency serves as well and the negative is safeguarded against breakage or disfigurement.

For the benefit of those not familiar with the methods of micro-photometry a brief word on principles will be given. A beam of light from an incandescent lamp, Fig. 10, passes through a photographic negative or transparency and is directed by a suitable optical system to a thermo-pile or other light sensitive element which is connected electrically with a moving coil galvanometer. The deflections of the galvanometer are photographically recorded on a sheet of bromide paper stretched around a drum. By moving the photographic plate and at the same time rotating the drum, a record is made on the bromide paper. The E.M.F. generated in the thermo-pile or light sensitive element is proportional to the intensity of the light falling on it and thus the deflections of the galvanometer will be proportional to the density of the negative. The magnitude of the galvanometer swing from

complete transparency to complete opacity is controlled by a variable resistance in the electrical circuit. For the purpose of our investigations the maximum swing has been arbitrarily set at 20 centimeters. The movement of plate and drum are coördinated by suitable gears so that the curve traced on the bromide paper bears a definite relationship to the movement of the plate. We have employed an enlargement of seven times. The instrument which we have used is the Moll recording micro-photometer.

FIG. 10.

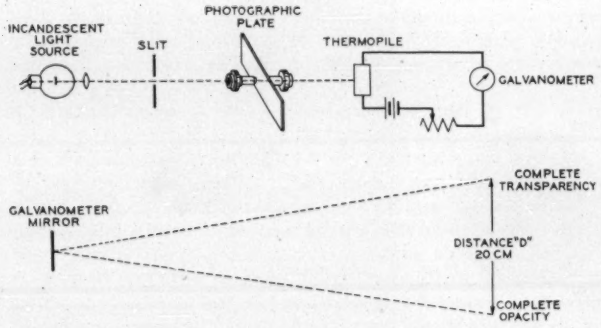
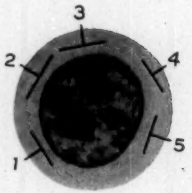


Diagram illustrating principles of the micro-photometer.

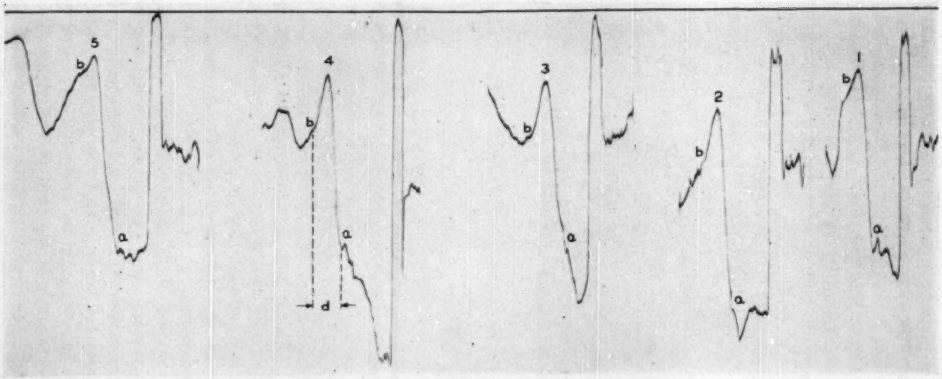
One or two applications of the method will be given to illustrate the manner in which ultra-violet micrographs of living cells may be analyzed.

If the junction of cytoplasm and nucleus of the cell shown in Fig. 11 is traversed at points 1, 2, 3, 4 and 5 the correspondingly numbered curves result. As the light pencil traversing the cytoplasm meets the juncture, there is an abrupt rise followed by a drop in the curve as the light beam starts to come out of the juncture and to enter the nuclear plasm. It will be observed that the curve does not fall to the same level as that recorded for the outside of the membrane, i.e., points *a* and *b* are not at the same level. From the form of these curves we are led to infer that the nucleus

FIG. 11.



1800 ×.



12,600 ×.

The application of microphotometry to the study of the nuclear wall of a living malignant tumor cell. Practically every detail of structure within a living cell is capable of critical analysis by this method.

is surrounded by a membrane or wall. My cytological friends will probably not view this as a startling deduction. The crest of the curve indicates the center of the nuclear membrane and the distance, *d*, the thickness of the membrane at a magnification of 12,600 times. The fact that the points *a* and *b* are not at the same level indicates that the material within the nucleus has greater absorptive power than the material of which the cytoplasm is composed. Positions 1 and 5 were chosen because at these points in the nucleus chromatin lies in contact with the inner wall of the membrane. The condition is at once reflected in the characteristic curve, as is evident. To the right of each curve a cusp appears. This results from the guide line ruled on the transparency for the purpose of facilitating measurements in the manner about to be described.

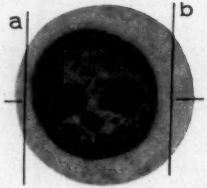
Figure 12 is a living rodent tumor cell in the resting stage. It is advantageous for purposes of measurement to rule two lines such as *a* and *b* on the transparency. As the traversing beam strikes these lines, cusps appear on the curve. Since the photograph has a magnification of 1800 times, and the curves are at an enlargement of 7 times, the magnification of the curve becomes 12,600 times. If it is desired to locate a boundary or detail of structure, proportional dividers set at the ratio of 1 : 7 may be used and measurements made from the cusps. Reversing the dividers to use the short arms on the transparency, the exact position of any detail can be quickly located.

An interesting application is the budding of a living yeast cell.

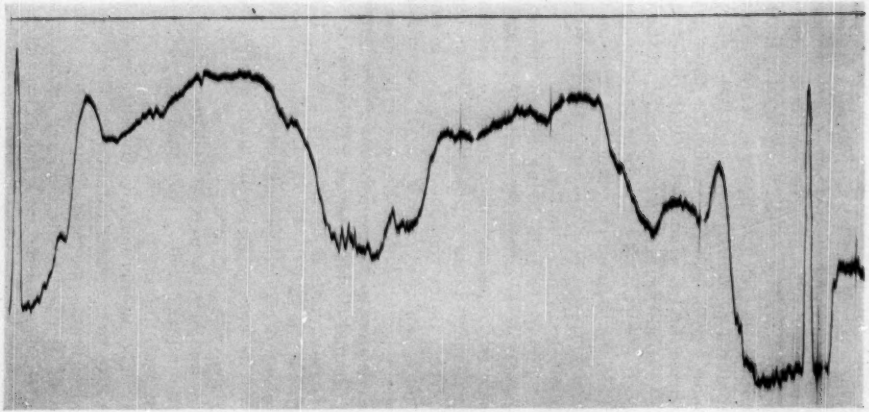
Figure 13 is a yeast cell in which a bud is forming from the mother cell. This micrograph is at a magnification of 2500 times.

The mother cell absorbs ultra-violet light of wave length $\lambda 2750$ to a greater extent than the bud. As these cells age, absorption increases. From this photograph it is quite evident that in the bud, cell organization has taken place. A traversal of the neck connecting mother and daughter cell discloses some irregularities in absorption. The material within the neck is relatively undifferentiated. Organization apparently takes place later in the bud.

FIG. 12.



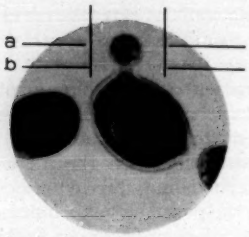
1800 X.



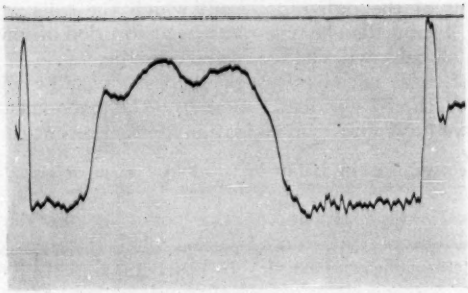
12,600 X.

Optical section of a living rodent tumor cell in the resting stage. The ultra-violet plate is printed as a transparency on process film and lines are ruled on the transparency as bench marks from which to measure. As the traversing beam of the microphotometer strikes these lines, cusps appear on the curve.

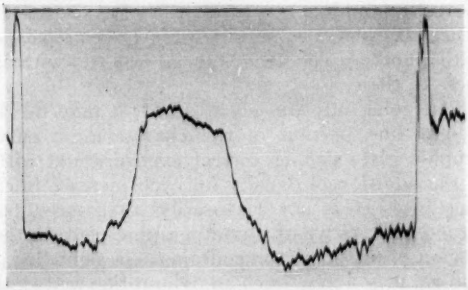
FIG. 13.



17,500·x



A-Bud



B-Neck

Optical section of a living yeast cell. Cell organization has taken place in the bud. The curve resulting from a traversal of the neck connecting mother and daughter cell discloses some irregularities in absorption but the material within the neck is relatively undifferentiated. Organization apparently takes place later in the bud.

Practically every detail of structure in an ultra-violet negative of a living cell is capable of critical analysis by this method. For example quite accurate measurements of minute details of structure can be made from them. Variations in the absorption or transmission of ultra-violet light by cellular detail can be easily noted. Variations in detail not readily apparent to the eye may be detected. In the study of chromosomes to which the ultra-violet microscope lends itself, these methods may prove particularly valuable.

Observations in the past few years have seemed to indicate that the absorption of certain living cells appears to vary with the state of health and perhaps the age and the seasonal variations of the individual from which the cells were dissected. It may also be true that the absorption of some cells, perhaps all cells, will change as the cells die.

All of these variables are open to study and exploration by the methods described. Some of the phenomena mentioned, we have under investigation at the present time.

COMPARISON OF LIVING CELLS ON THE BASIS OF THEIR RESPONSE TO ULTRA-VIOLET RADIATIONS.

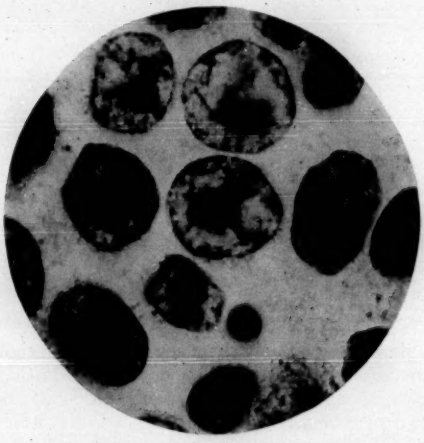
These methods suggested the possibility of comparing cells of different types on the basis of their responses to a given ultra-violet radiation. It has been observed that all cells do not transmit or absorb ultra-violet light to the same degree. It is obvious that two photographs, each of a different cell, would not necessarily bear a relationship to each other, because the densities of the two plates would vary with photographic technique as well as with inherent differences in the cells.

Without going into too much detail, it may be said that the straight line portion of the characteristic curve of a photographic plate defines correct exposure and within this portion the addition of density for each increase in exposure is a constant. It is not necessarily an assured fact that the characteristic curve of a photographic plate in the ultra-violet region of the spectrum contains a straight line portion. However, we may accept such an assumption and experiment accordingly.

If two details of structure could be found which are always present in a given type and stage of cell, then the relative densities of these two details on a given properly exposed plate should bear about the same relationship to each other as their relative densities on any other properly exposed plate bear to each other. The problem was to find two details of structure common to a given type and stage of cell and then to find a way to compare them.

Experimental rodent tumor cells, Fig. 14 for example, show well defined nuclei in the resting stage. It has been shown that the nuclear wall reveals a characteristic curve.

FIG. 14.



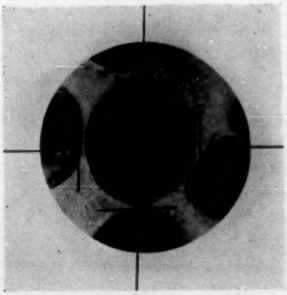
Optical section of experimental living rodent tumor cells photographed with the ultra-violet microscope. The magnification is 1800 X.

A normal resting cell is optically sectioned, and a photograph selected, Fig. 15, which represents the structure on a plane passing approximately through the center of the nucleolus. A transparency is made and guide lines ruled indicating the paths to be traversed by the light beam.

If a large number of paths all passing through the center of the nucleolus were traversed and the varying diameters recorded, the summation of all the absorption curves would be a close approximation of the total ultra-violet light absorbed on the given plane.

For all practical purposes, it has been found that if the cell contains a single nucleolus, two paths such as those indicated will give a reasonable approximation for comparative purposes. If two nucleoli are present in the cell,

FIG. 15.

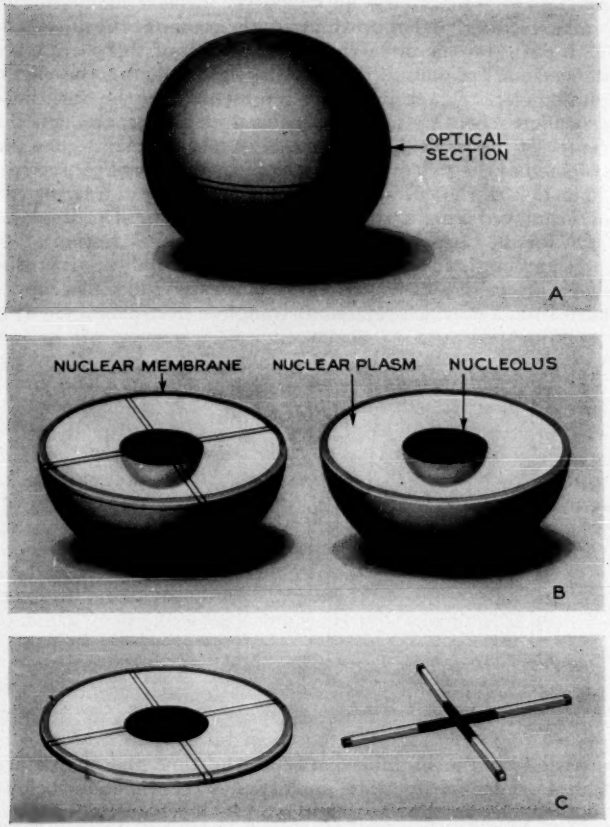


For the purpose of evaluating relative energy relationships, a normal resting cell nucleus is sectioned and a photograph selected which represents the structure on a plane passing approximately through the center of the nucleolus. A transparency is made and guide lines ruled indicating the paths to be traversed by the light beam.

one path should traverse both; a second path at right angles should traverse one nucleolus and a third path, also at right angles, should traverse the other. It is not necessary to have the paths exactly at right angles but it is important to have the paths intercept the nuclear wall approximately at right angles. Otherwise the curve would indicate a thicker nuclear wall than actually exists.

Figure 16 is a model of a resting living tumor cell nucleus greatly enlarged. The band of "A" represents an optical section plane about 1/4 micron in thickness. A photograph would be taken of the detail on this plane without in any way interfering with the normal living functions of

FIG. 16.

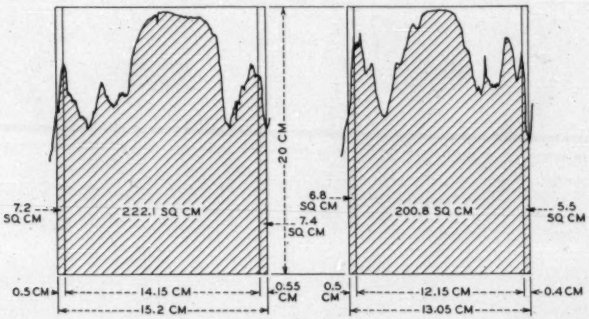


A model of a resting living tumor cell nucleus greatly enlarged. The optical section is represented by the band in "*A*." Details of structure on the section are represented in "*B*." In "*C*" at the left the optical section is shown as though removed from the nucleus, and at the right the two tiny bands of protoplasm to be traversed by the light beam are shown as though removed from the living optical section.

the cell, so far as one can judge. The details of structure are represented at "B" in which the nuclear membrane or wall is pictured and approximately the center of the nucleolus. Two paths on the ultra-violet photograph of this section are defined for "scanning" by the tiny light beam of the microphotometer. These paths are represented by the dark lines crossing each other at right angles and passing through the center of the nucleolus. Our energy measurements then are confined to the two or more paths through the optical section. Thus it is as though we delved into the center of a living cell and removed from it two or more tiny ribbons of protoplasm "C" for the purpose of measurement and investigation.

Characteristic curves are obtained as indicated in the diagram of Fig. 17*A*. To these curves is added the upper horizontal line which represents complete transparency. It is

FIG. 17*A*.



Characteristic curves resulting from analysis of the nucleus shown in Fig. 16. Curve enlargement 12,600 X.

recorded on the bromide paper at the time the curves are traced. Parallel to this and twenty centimeters below, another line is drawn which represents complete opacity. It now remains to locate the vertical lines representing the outer surface of the nuclear wall. This is done by the proportional divider method and very carefully checked to be sure that the location is made as accurately as possible.

Of course it is not possible in every case to locate the inner surface of the nuclear wall because chromatin often lies in contact with the inner surface. The cusps of the nuclear wall are always present and we may assume that they indicate the center of the nuclear wall. Perpendiculars are then drawn through the cusps.

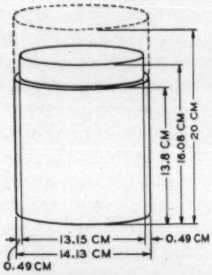
The area of the rectangle may be taken as representing the total radiant energy absorbed or transmitted; the area below the curve, the energy absorbed; and the area above, the energy transmitted. The area below the curve may be regarded as representing the energy absorbed in the nuclear contents and the energy absorbed in the nuclear wall. While only the other half of the nuclear wall is used in our measurements, this serves for comparative purposes.

The diameter of the nucleus is measured, also the thickness of the nuclear wall. By means of a polar planimeter the areas representing nuclear wall absorptions and nuclear contents absorption are obtained. These are recorded on the diagram as indicated. From results secured by this method a cylinder may be constructed which averages conditions. Obviously, the cylinder will be twenty centimeters in height and its outside diameter will be proportional to the average outside diameter of the nucleus as obtained from measurements of the curves. The nuclear membrane can be represented by an outer shell of a thickness equal to the average measurements secured from the diagrams. Average heights representing nuclear wall absorption and nuclear contents absorption are obtained by dividing respective areas by widths.

Conditions may be represented by a geometrical drawing Fig. 17*B*. Simple calculations give the volumes of the portions of the cylinder represented. The drawing takes into account the average diameter of the nucleus; the average wall thickness; the absorption occurring in the wall of the nucleus; the absorption occurring in the nuclear contents and the total energy recorded for the particular optical section selected for analysis.

Figure 18 is a model representing one of the cells analyzed in this manner. Table II shows the results obtained by analyzing a number of mouse carcinoma cells. It will be

FIG. 17*B*.

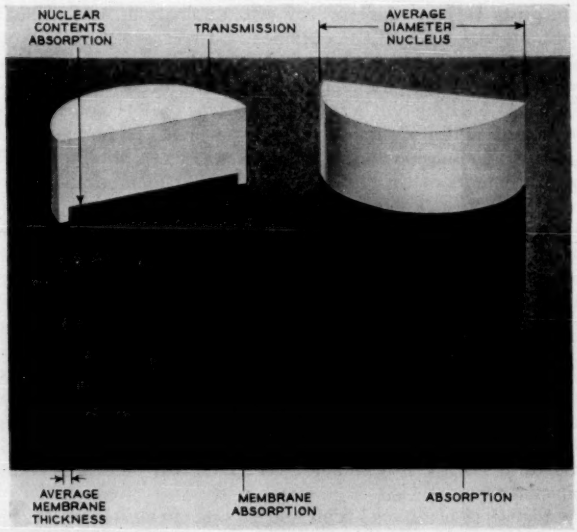


	CU CM	PER CENT
NUCLEAR MEMBRANE ABSORPTION	290	11.7
NUCLEAR CONTENTS ABSORPTION	2184	88.3
TOTAL ABSORPTION	2474	100.0
NUCLEAR TRANSMISSION	562	21.1
NUCLEAR ABSORPTION	2474	78.9
TOTAL	3036	100.0

MOUSE CARCINOMA, LIVING CELL
STRAIN $\frac{48}{183B}$
INOCULATED ------ APR. 7, 1932
OPERATED ------- MAY 6, 1932

A geometrical drawing representing the energy absorbed and transmitted by the optical section of Fig. 16. The solid was calculated from data furnished by the curves of Fig. 17*A*. Curve enlargement 12,600 ×.

FIG. 18.



A model constructed according to the drawing of Fig. 17 and showing in true relationship the energy absorbed in nuclear wall and nuclear contents and the average nuclear wall thickness and average nuclear diameter.

observed that the diameters, the per cent. transmission and the per cent. absorption vary. Variations in transmission and absorption are to be expected because of variations in

TABLE II.

Rodent Carcinoma Cells.

Curve enlargement 12,600 ×.

Strain Designation.	Diameter Nucleus. (Cm.).	Per Cent. Transmission.	Per Cent. Absorption.	Per Cent. Absorption Nuclear Membrane.	Per Cent. Absorption Nuclear Contents.
206	13.42	11.0	89.0	12.0	88.0
48	12.32	21.3	78.7	11.1	88.9
48	12.65	16.3	83.7	11.4	88.6
48	13.12	15.9	84.1	10.7	89.3
48	14.90	19.7	80.3	10.5	89.5
48	14.13	21.1	78.9	11.7	88.3
48	13.54	7.6	92.4	11.5	88.5

photographic technique. The per cent. absorption in nuclear membrane to per cent. absorption in nuclear contents remains quite constant. One might reasonably expect the differences to be accounted for by instrumental and experimental errors.

Table III gives the analysis of a group of rat sarcoma cells. The per cent. absorption in nuclear membrane to

TABLE III.

Rodent Sarcoma Cells.

Curve enlargement 12,600 ×.

Strain Designation.	Diameter Nucleus. (Cm.).	Per Cent. Transmission.	Per Cent. Absorption.	Per Cent Absorption Nuclear Membrane.	Per Cent Absorption Nuclear Contents.
R-39.....	13.20	5.9	94.1	12.3	87.7
R-39.....	15.81	13.0	87.0	11.4	88.6
R-39.....	16.92	7.5	92.5	13.51	86.49
R-39.....	9.69	8.0	92.0	12.5	87.5
R-39.....	12.5	16.0	84.0	11.4	88.6
R-39.....	13.03	18.3	81.7	12.5	87.5

per cent. absorption in nuclear contents appears quite constant and is of the same order as indicated for the mouse carcinoma cells of Table II.

In Table IV are given the results of analyzing three transparencies of the same cell, the only variable being the difference in the relative density of the transparencies. In other words, time of exposure was varied to see what the

TABLE IV.

Rodent Carcino-Sarcoma Cells.

Curve enlargement 12,600 ×.

Strain Designation.	Time Exposure Plate.	Per Cent. Transmission.	Per Cent. Absorption.	Per Cent. Absorption Nuclear Membrane.	Per Cent. Absorption Nuclear Contents.
256.....	2½″	43.4	56.6	11.8	88.2
256.....	5″	17.2	82.8	11.0	89.0
256.....	10″	5.6	94.4	12.6	87.4

effect might be experimentally. The per cent. absorption in nuclear wall and in nuclear contents seems to check quite well with results shown in Tables II and III.

One naturally wonders whether all cells show the same relationship and whether they are of the same order. Certainly our work has not progressed to the point where such a question can be answered. The indications are from some preliminary work on living fœtal mouse cells that per cent. absorption in the nuclear wall is of the order of about 20 per cent. Analysis of fixed and unstained rodent tumor cells corresponding to those listed in Tables II and III indicate that in the fixed material the absorption in nuclear wall is of the order of about 22.5 per cent. rather than the 12 per cent. approximately indicated for living cells.

THE IRRADIATION OF LIVING CELLS WITH CERTAIN MONO-CHROMATIC ULTRA-VIOLET RAYS AND SOME OF THE EFFECTS PRODUCED.

The ultra-violet microscope is a mono-chromatic system, designed for wave length λ2750. Little is known about the effects of other wave lengths between λ3000 and λ2000. Optics will soon be available for other wave lengths in this range. A group of strong lines lying in this region of the spectrum has been selected and optical systems are being corrected for them. What will be the response of living things to these wave lengths? Will organic matter be opaque to the

short wave lengths or will the cells be killed by them? What may we expect? Some preliminary studies have been made.

The wave lengths given in Table I were chosen because they could easily be isolated with the mono-chromator. A simple plant cell organism, *Glæocapsa*, was chosen as the material, because this cell had already been studied to some extent at wave length λ2750. It was recognized that optics corrected for λ2750 would be deficient in their performance at other wave lengths but some results as to the behavior of the cells might be obtained.

It was found that when photographed with wave length λ2573, the absorption of the organism increased but the definition in the photographs was as good as in the photographs taken at λ2750. When an attempt was made to use the λ2300 line the absorption was very strong and the photographs were not sharp or distinct. This might be due to a multiple image effect because of the large number of closely grouped lines comprising the λ2300 group, each line forming a different image and the images being superimposed. It might also be due to the fact that the lens system was not corrected for a line in that region of the spectrum.

We were confronted with the experimental fact, however, that a lens system corrected for λ2750 gave excellent results when used with a wave length 200 Ångstrom units further down in the spectrum, but when used at another wave length some 200 Ångstrom units still further down, the image became very indistinct. There appeared to be some other contributing cause.

A study of a series of photographs of optical sections through a group of these organisms photographed with wave length λ2300 disclosed that the cells had been affected by this radiation. When optical section photographs are taken, the organism is exposed to the ultra-violet light for a few seconds for the first exposure. The light is then excluded from the microscope, during which time adjustments are made for the next exposure at a different level. The light is then admitted for the second exposure and so on until the desired number of photographs have been taken. The specimen is acted upon by the ultra-violet light only during the

actual time of exposure which may vary from five to thirty seconds depending on conditions and on the material under investigation. It is obvious that each exposure in an optical section sequence adds an increment of time during which the material is irradiated with ultra-violet light.

The optical section photographs, when laid out in order, disclosed that under the action of wave length λ2300 the spacing between cells increased with the time of irradiation and the final result seemed to be a shrinkage in the size of the cell and finally a general disintegration.

Only a very small field of circular area on the slide was irradiated by the ultra-violet light. Cells in other fields were not exposed to the light and if the slide were moved after a field had been irradiated for six or eight minutes, a circular area would be evident in which the cells had been disintegrated by the irradiation but surrounding this area were normal cells.

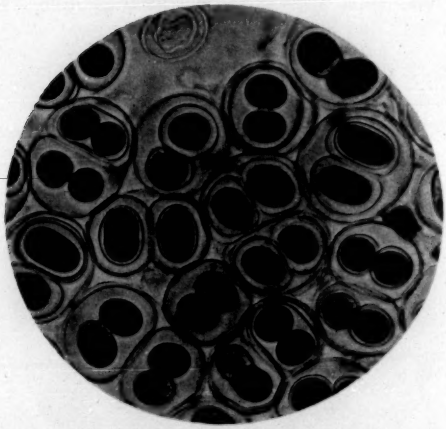
Repeating similar experiments with wave length λ2265 the action became almost instantaneous. For a second or so, while under visible observation with the fluorescent ocular, the cells seemed agitated or strained and then they literally jumped some five or ten times their diameter; this distortion was followed by shrinkage and finally disintegration. The action was so fast that there was little hope of recording it photographically.

Since wave length λ2750 did not affect the cells, the reactions to wave length λ2300 were studied by photographing the specimen with wave length λ2750, irradiating it for a given time with wave length λ2300 and rephotographing with wave length λ2750. By irradiating and photographing in regular sequence, a series of photographs could be secured showing the cumulative effects of irradiation. This method of study has disclosed some interesting information.

Figure 19 is an ultra-violet micrograph of glœocapsa at a magnification of 1800 × taken with wave length λ2750 for which the optical system of the microscope is corrected.

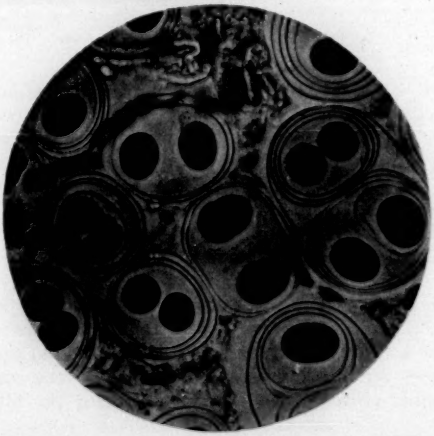
Figure 20 is a similar photograph taken with wave length λ2573. The absorption is stronger for this wave length but the definition appears good.

FIG. 19.



An ultra-violet micrograph of *Glæcapsa* at a magnification of 1800 × taken with wave length λ2750 for which the optical system of the microscope is corrected.

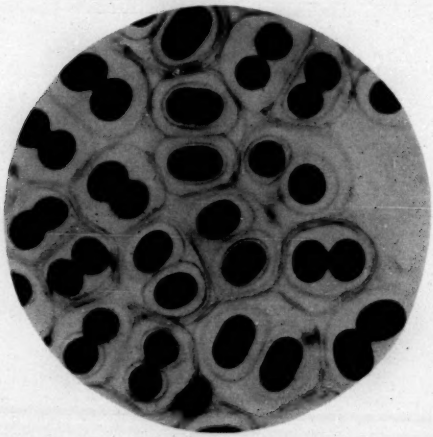
FIG. 20.



A photograph similar to Fig. 19 but taken with wave length λ2573. Magnification 1800 ×.

Figure 21 is a similar photograph taken with wave length λ2300. The cells appear to be quite opaque. The outlines are hazy and indistinct.

FIG. 21.



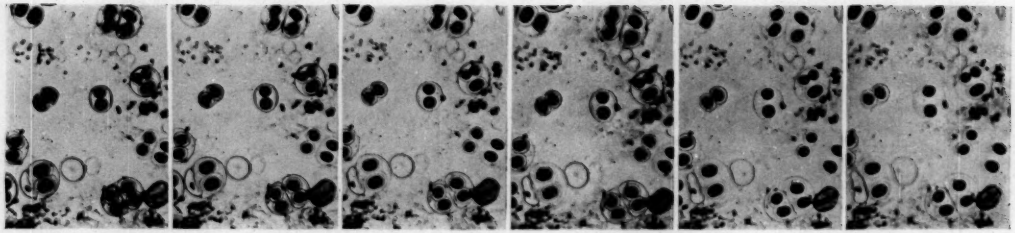
A photograph similar to Fig. 19 but taken with wave length λ2300. Magnification is 1800 ×. The absorption is stronger for this wave length but definition is not good. The outlines appear hazy and indistinct.

Figure 22 comprises 6 photographs from an optical section sequence. The wave length used was λ2300. It will be observed that as the irradiation time increases, separation of component members takes place. It is only necessary to follow a given cell from left to right in the arrangement of the photographs to see that this is so.

Figure 23 shows a group of cells photographed with wave length λ2750 before and after a short period of irradiation with wave length λ2265.

At the present time we lack exact knowledge of the intensity of the ultra-violet light for each of these wave lengths as it passed through the specimen. If I were to judge it by appearances on the fluorescent ocular or by the response of photographic plates especially sensitized for the ultra-violet

FIG. 22.



1 2 3 4 5 6

Six photographs from an optical section sequence. The wave length used was λ2300. Each exposure required ten seconds and between exposures the cells were irradiated for two minutes. As the irradiation time increases separation of component cell members takes place. The magnification is 500 ×.

FIG. 23.

1 2

A group of cells photographed with wave length λ2750 before and after a very short period of irradiation with wave length λ2265. The magnification is 500 ×.

region I should say that the intensities were not greatly different. The eye is not a good judge of distances and intensities, and photographic methods have limitations. Precise data on the order of intensities are needed but these measurements have not been made as yet. It may be that the effects observed are due entirely to differences in intensity of irradiation or perhaps specific wave length or frequency may be the causative factor. Some years ago we reported that certain single cell organisms were almost instantly killed by wave length λ2750 whereas other organisms of about the same order were only mildly disturbed and still others seemingly not affected at all.

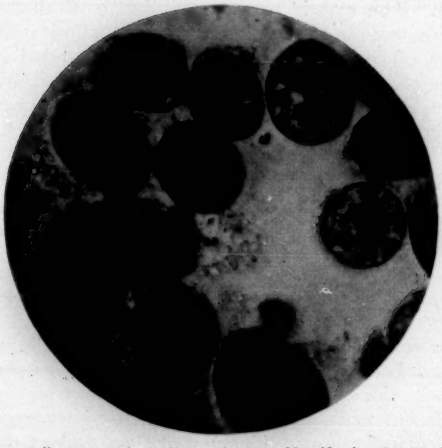
CERTAIN MONO-CHROMATIC ULTRA-VIOLET RAYS ARE EXTREMELY LETHAL TO MALIGNANT TUMOR CELLS.

Our investigations, which have been in progress for several years, have been extended and some results have been secured on the behavior of living rodent tumor cells when irradiated with different wave lengths in the ultra-violet region. We have failed to find any evidence that these rodent tumor cells are affected by exposures to ultra-violet light of wave length λ2750 of the intensity and duration of exposure which I have employed in ultra-violet microscopy. Nor have we found that wave length λ2573 of the intensity and duration of exposure employed has any effect. We have selected several representative photographic sequences to illustrate the application of the methods employed and they are described as follows:

"Photomicrographs of living cells from malignant growths show clearly the differences between carcinoma, Fig. 24 and sarcoma, Fig. 25. When such cells (Fig. 26) are exposed to short wave lengths (λ2300, λ2265, λ2144) there is immediate shrinkage followed by death. Irradiation of such cells for 2 minutes with wave length λ2300 (Fig. 27) has caused the cells to shrink and shrivel."

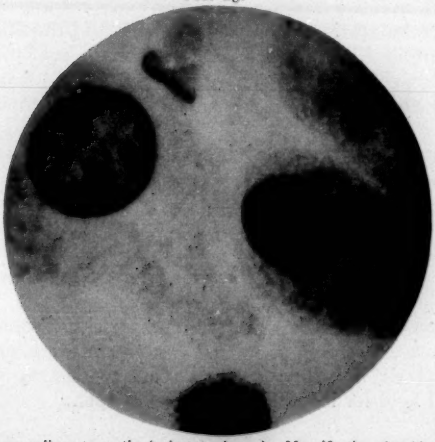
It seems evident that certain of these short wave lengths of light are extremely lethal to experimental rodent tumor cells. Relatively mild exposures seem to destroy the cells. A fruitful field for investigation appears open.

FIG. 24.



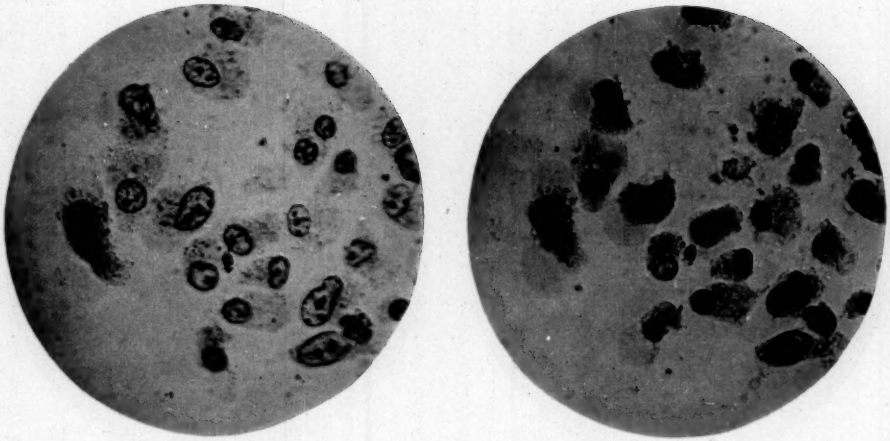
Living cells from malignant growths (rodent carcinoma). Magnification 1800 ×. The cells are not affected by wave length λ2750 used for ultra-violet photography.

FIG. 25.



Living cells from malignant growths (rodent carcinoma). Magnification 1800 ×. The cells are not affected by wave length λ2750 used for ultra-violet photography.

Fig. 26.



1 2

When living malignant rodent tumor cells are exposed to short wave lengths (λ2300, λ2265, λ2144) there is immediate shrinkage followed by death. These cells were photographed with wave length λ2750 before and after a 20 second irradiation period with wave length λ2265.

FIG. 27.

Malignant rodent tumor cells photographed with wave length λ2750 before and after a two minute irradiation period with wave length λ2300. The irradiation with this wave length has caused the cells to shrink and shrivel almost beyond recognition.

COUPLING OF X-RAY APPARATUS AND ULTRA-VIOLET MICROSCOPE WILL ENABLE ONE TO DETERMINE SPECIFIC REACTIONS OF LIVING CELLS TO X-RAYS.

I have discussed with X-ray experts the design of X-ray equipment to be coupled with the ultra-violet microscope. The object in mind is to irradiate living cells with X-rays of known characteristics and at the same time keep the cells under observation with the ultra-violet microscope. I have been assured that the design suggested is practical. A storehouse of new information may thus be opened for investigation through the coupling of X-ray apparatus and the ultra-violet microscope.

A PRECISION HIGH POWER METALLOGRAPHIC MICROSCOPE.

There are certain late developments in metallography which I shall describe briefly.

In 1927, the design of an advanced metallographic microscope became of interest. The plan was to make this microscope as nearly perfect mechanically as possible and to incorporate in the design the most efficient optical systems that could be devised. The plans were taken to Germany and discussed with the scientific staff of Carl Zeiss whose coöperation was sought in the final design and construction. The commission was accepted and work was started late in 1927. The actual design and construction of the apparatus required approximately four years during which time close consultation with the makers was maintained.

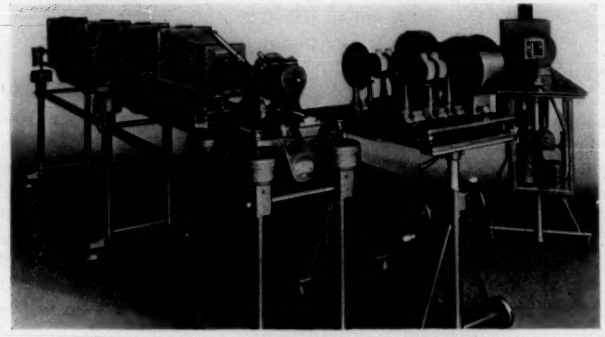
Recently a [4] paper was published on the design and construction of this precision high power metallographic apparatus.

If we summarize the desirable characteristics in a precision apparatus for photographing the structures of metals at magnification from 4000 to 6000 diameters, we require great mechanical stability, freedom from creep, absolute freedom from outside disturbances, the means to illuminate the specimen with light of any selected wave length or group of wave lengths within the visible spectrum, and the highest order of achievement in optical equipment.

The entire equipment is mounted on three stands as illustrated in Fig. 28. The microscope parts and the camera are mounted on carrier rails or tubes which are rigidly joined

together by massive yokes. The carrier rails rest on eight shock absorbers. The balance and mounting completely insulates the carrier rails and associated apparatus from vibratory disturbances. Heretofore, with older conventional apparatus, time of exposure was limited to about one and one-half minutes because vibratory disturbances, creep and lack of mechanical stability caused the image to go out of focus if time of exposure was greatly increased. With this new apparatus exposures as long as thirty minutes have been

FIG. 28.



A precision high power metallographic apparatus developed in coöperation with the Zeiss Works, Jena, Germany.

made and crisp brilliant images secured at very high magnifications.

The illuminating apparatus is mounted on two separate stands. The first apparatus comprises an arc light train and a mercury vapor lamp train, either of which may be brought into immediate alignment with the vertical illuminator merely by sliding the table top on its rails. Stops and catches are provided at each end of its travel to insure proper alignment. By centering the table top neither train is in alignment but space is provided for light from the second illuminating stand to reach the vertical illuminator. This second illuminating apparatus is a mono-chromator con-

sisting of a spark gap and a suitable optical train for spectroscopically decomposing the light into the slit images of its characteristic line spectrum. The desired slit image is brought to bear on the vertical illuminator. Thus it is possible to illuminate the specimen with a single wave length of light; with a group of wave lengths or a broad band from any part of the visible spectrum.

The reason for this control of the illuminating beam is due to the fact that the very best apochromatic objectives are only an approximation at bringing all of the different wave lengths to a common focus. If it is desired to work with light of a given wave length for the purpose of increasing resolution or because selective absorption of that particular wave length or wave lengths by the specimen promotes contrast in the details of structure, it should be possible in a precision apparatus to exclude all other wave lengths. In theory at least, the objective should be able to function better if all wave lengths other than the particular ones desired are excluded. Experimental work with the apparatus has demonstrated that this is so in practice.

The optical system of the microscope is unique. It is arranged so that objectives corrected for 190 mm. tube length or those corrected for an infinity tube length may be used. The infinity objectives are a recent development and were expected to yield better images for reasons which have been discussed elsewhere. Our investigations throughout the past two years have demonstrated the superiority of these objectives over those corrected for a definite tube length. The infinity objectives produce a real image at infinity but the rays, after passing through the vertical illuminator, are intercepted by a telescope objective which brings them to a focus within the ocular. The eye piece of the microscope therefore comprises a Keppler telescope consisting of a telescope objective and a low power photo-ocular.

THE MONO-BROM-NAPHTHALENE OBJECTIVE.

In this apparatus we have made use of the mono-brom-naphthalene objective of NA 1.60 which has recently been corrected for the blue region of the spectrum. This metallo-

graphic objective represents the highest achievement yet attained in the correction of a high aperture objective for a restricted region of the spectrum. We have been at work for about ten years perfecting technique, apparatus and abrasives which would enable us to use this objective successfully and my metallographic contribution to this evening's lecture will be to show for the first time the results which have recently been achieved with this objective.

The very finest apochromatic objectives available for metallographic work have a numerical aperture of 1.40. The aperture of this new objective is 1.60 and by virtue of this high numerical aperture it should have superior resolving powers. Figure 29 illustrates how resolving power varies with numerical aperture.

The history of this objective is interesting. It was brought out in 1889 by Professor Abbe and experimentally it was made available as early as 1885. Dr. van Heurck,[5] a continental microscopist of note, described his experiments with two of these objectives which had been furnished him for test. His work was confined entirely to diatoms and so far as I am aware his published photographs and his observations on the performance of the objective constituted its sole record of achievement.

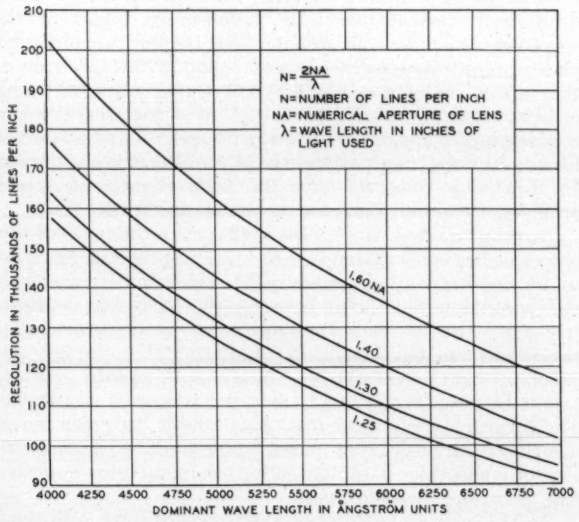
The reason is not hard to find. At the time this objective was brought out practically all microscopic specimens were mounted as transparent objects. Metallography, as we know it today, did not exist. Scientists were just beginning to study metals with the microscope and technique was very crude. To utilize the high aperture objective with transparent specimens presented some real problems in connection with the mounting of specimens.

Czapski[6] presented a paper before the Royal Microscopical Society in 1889 under the subject "On an objective with an aperture of 1.60 NA made according to the formulæ of Professor Abbe in the Optical Factory of Zeiss." He also published other papers in the German Scientific press. Among his remarks the following appears:

"This is not the place to dilate on what can be done with objectives of this kind. The results which Dr. van Heurck has already obtained in the use of them led in any

case to the hope that in spite of the great difficulty of their use, they will afford valuable aid for certain problems of microscopy. It will be a question for connoisseurs to decide whether in other branches of microscopical research besides that of diatoms an equally marked advance on that previously reached can be obtained."

FIG. 29.



Relationship of theoretical resolving power, numerical aperture and dominant wave length of light used.

Theoretically, at least, this objective offered a new approach to the study of matter but practically it failed of accomplishment and soon passed as a scientific curiosity. I am informed that the special glasses required for its construction were diverted to other purposes; the formulæ were filed away and the matter lay forgotten for many years.

The development of high power metallography eliminated most of the difficulties which at first surrounded the use

of this objective, for in metallography one deals with opaque objects which are separated from the front lens only by the immersion fluid. When it seemed probable that the theoretical limit of resolution with the apochromats of NA 1.40 would soon be reached, we asked the Zeiss Works to revive the mono-brom-naphthalene objective for metallographic purposes.

Two of these objectives were constructed to our order. They were corrected for the yellow-green region of the spectrum which was disadvantageous because photographic plates are not as sensitive in this region of the spectrum as they are to the blue rays and by decreasing the wave length of light resolution is also promoted. For use with the new metallographic apparatus these objectives have been corrected for infinity tube length and for the blue region of the spectrum. In these objectives we have the highest order of optical achievement yet attained for the visible spectrum.

It may be interesting to know that even the name of this objective has suffered and it is no longer a proper designation so far as our work is concerned. The name comes from the immersion fluid used between the front lens and the specimen. In our metallographic work we discovered that the immersion fluid deteriorated, presumably through the effects of light or possibly by contact with metals. At any rate it becomes turbid due to minute particles in suspension. These particles before the front lens exhibit Brownian movement and practically ruin photographic work. The substitution of mono-chlor-naphthalene for the mono-brom-naphthalene overcame the difficulty.

In the early metallographic development work with these objectives, it soon became apparent that a higher order of resolution would not be achieved solely by more powerful optical systems. One must refine methods for the preparation of metallurgical specimens and for focusing the specimen once it is properly prepared. In metallography there is no particular point in applying these very high aperture objectives to structures which are capable of resolution by lower power optical systems. For example the constituent pearlite is a laminated structure of iron carbide in ferrite. The high aperture lens does not add more carbide lamellæ than have

been seen with an apochromat of NA 1.40. The lens merely develops detail on the surface of the ferrite and carbide. As an experiment in testing resolving power, pearlite proves interesting but we develop little information of practical significance so far as metallurgy is concerned.

However, there are alloys in which precipitation hardening is manifested; alloys such as the chrome-irons which develop poor physical properties throughout a narrow range of heat treatment and numerous other problems in metallography with which these objectives might be expected to cope. All of these problems appear to involve the precipitation of an exceedingly minute hard constituent in a soft matrix. By suitable heat treatments the particles generally can be caused to coalesce and to grow in size. As the particles increase in size the spacing between particles becomes greater and the physical properties of the metal change.

When the particle size in a hardenable alloy is of the order of about 300 atom diameters the alloy develops ductility and softness so that the critical particle size for maximum hardening effect must be very much smaller than this.

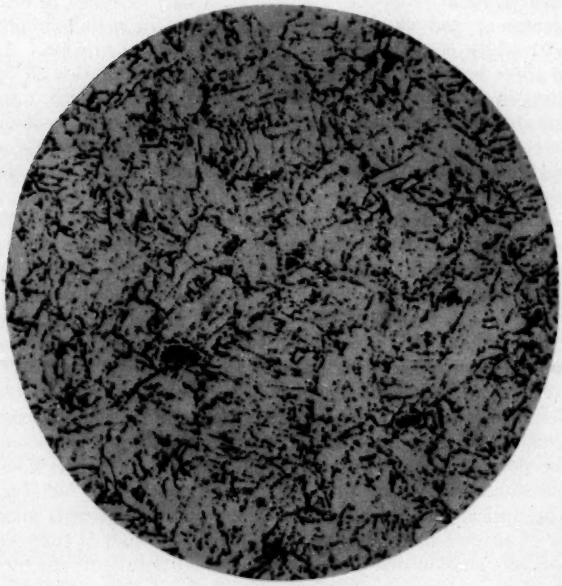
If we are to photograph a detail of structure about 200 atoms in diameter, it is obvious that the specimen must be prepared with the greatest of care; otherwise the imperfections in polish will be of a greater magnitude than the detail we hope to photograph. Consequently the photograph would show roughness and unevenness in the specimen and the details of structure would be obscured. Another complication enters the problem in the matter of focusing. The optical and mechanical stability of the apparatus must be of an extremely high order as focus obviously is confined to a very shallow plane and with such small details of structure the eye encounters difficulty. Generally in such specimens many small details of structure are photographed which the eye did not discover in the focusing operation.

Figure 30 is a micrograph at 1000 diameters of a specimen of chrome-iron quenched in oil from 1750° F. and drawn for 2 hours at 1450° F. I shall use this specimen to illustrate how resolution has been improved through use of the mono-brom-naphthalene objective of NA 1.60. This particular photo-

graph even at moderately high magnification fails to disclose the condition which we seek.

Figure 31 is the same specimen photographed at 4000 diameters with the infinity corrected objective of NA 1.40. This photograph shows, I believe, the very highest order of

FIG. 30.



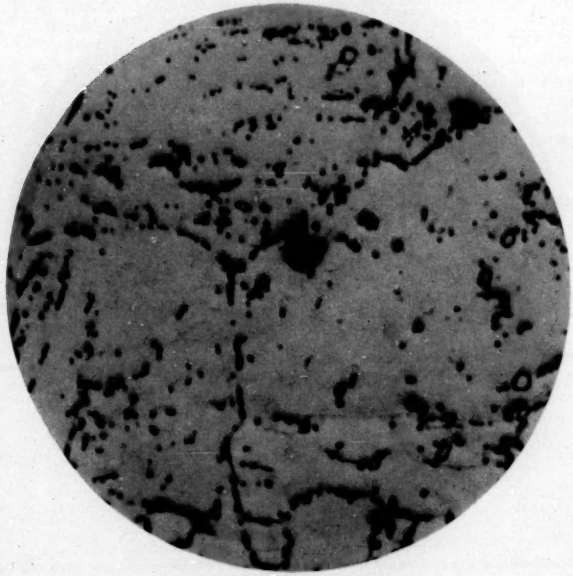
Structure of chrome-iron quenched in oil from 1750° F. and drawn for two hours at 1450° F. Magnification 1000 X.

resolution ever achieved with the very best apochromatic system. You will note however, that grain boundaries and crystallographic planes show dark streaks. Also, please form a mental picture of the isolated carbide particles. Note generally their size and the definition of their outlines. Are

the dark streaks and lines single carbides or are they groups of carbides or perhaps are they dirt and solid non-metallic inclusions? The isolated particles measure about 60 mmu in diameter or if you prefer say 200 to 300 atom diameters.

Figure 32 is the same specimen photographed with the mono-brom-naphthalene system of NA 1.60. The isolated

FIG. 31.

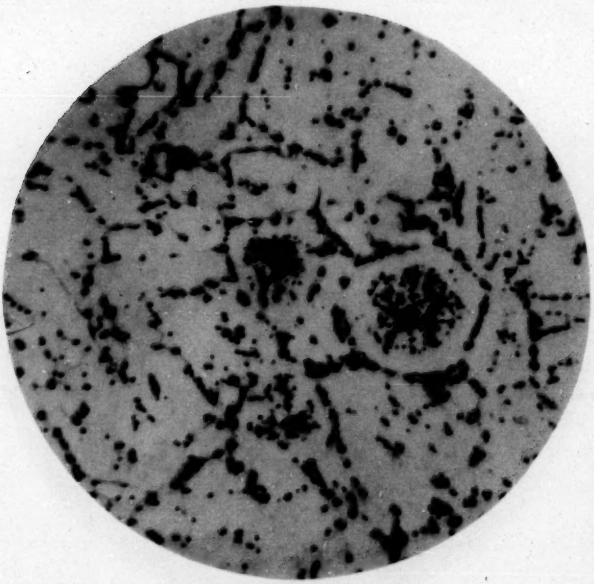


The same specimen as Fig. 30 but photographed at a magnification of 4000 times with the apochromatic objective of NA 1.40.

carbide particles now appear smaller than in the preceding micrograph and the boundaries and crystallographic planes are no longer revealed in places as solid black streaks but as minute chains of isolated carbide particles completely surrounded with the ductile ferrite. As in the preceding micrograph the magnification is 4000 diameters.

This new system just recently brought to practical application after nearly fifty years of endeavor provides science with a new tool for metallographic research. This system and the new precision high power metallographic

FIG. 32.



The same specimen as Figs. 29 and 30 but photographed at a magnification of 4000 times with the mono-brom-naphthalene objective of NA 1.60.

apparatus constitute the most powerful combination ever devised. They probably will be surpassed only when we succeed in developing a more powerful source of ultra-violet light so that we may apply more successfully these short wave lengths of light to metal specimens.

REFERENCES.

1. F. F. LUCAS: "An Introduction to Ultra-violet Metallography," *Transactions American Institute of Mining and Metallurgical Engineers*, Vol. LXXIII, 1926.
2. F. F. LUCAS: "The Architecture of Living Cells," *Proceedings, National Academy of Sciences*, Vol. 16, 1930.
3. F. F. LUCAS AND M. B. STARK: "A Study of Living Sperm Cells of Certain Grasshoppers by Means of the Ultra-violet Microscope," *Journal of Morphology and Physiology*, Vol. 52, No. 1, 1931.
4. F. F. LUCAS: "On the Design and Construction of a Precision High Power Metallographic Apparatus," *Transactions of the American Society for Steel Treating*, Vol. XXI, No. 12, 1933.
5. VAN HUERCK: "The New Optical Contrivance of the Messrs. Zeiss and the Structures of the Diatomic Value," *Annales de la Société Belge de Microscopie*, Vol. II, 1884–1885.
6. CZAPSKI: "On an Objective with an Aperture of 1.60 NA (Monobromide of Naphthalene Immersion) Made according to the Formulæ of Professor Abbe in the Optical Factory of Carl Zeiss," *Journal Royal Microscopical Society*, 1890.

Something New in Metallic Mirrors.—(*Science Service.*) A new type of metal-front mirror has been recently developed by DR. H. W. EDWARDS, physicist in the University of California at Los Angeles. In the manufacture of this mirror a piece of glass, and near it a piece of aluminum alloy are placed together in a large airtight enclosure. A high vacuum is then produced, the pressure in the chamber being reduced to one-ten millionth of its former value. The alloy is then electrically heated to a very high temperature, and readily evaporates into the extremely rarefied air. The metallic vapors find a rather free and unobstructed path over to the cool glass, where they condense to form a brilliant mirror.

This new type of reflector is known to movie camera operators as the "pancro" mirror because it reflects all colors alike. What is more, the mirror reflects light with approximately 93 per cent. efficiency. The common silver mirror, when operated from the metal side gives approximately the same efficiency with red light, but only 81 per cent. with violet light. Viewed through glass, still lower efficiency is observed. The alloyed metal of the pancro mirror, which is amenable to a special heat treatment, thereby acquires great resistance to deterioration without appreciable loss in power of reflection. The open surface, unhampered by the usual glass refractions and absorption, gives properly colored, realistic images not seen hitherto by ordinary mirror gazers.

With the aid of pancro mirror surfaces, motion-picture producers hope to effect considerable economy in the quantity of electric energy used for illumination, perhaps a saving as high as 50 per cent. The low efficiency of silvered reflectors for blue and violet light is thus overcome.

C.

Retention of Dichromate by Glassware.—According to EDWIN P. LAUG (*Ind. and Eng. Chem., Analytical Edition*, 1934, VI, 111–112) when glassware has been cleansed with "cleaning solution," which contains potassium dichromate and sulphuric acid, and then rinsed seven times with tap water and three times with distilled water, traces of dichromate are still retained within the glass. This residual dichromate is removed from the glass most readily by boiling with several successive portions of water, allowing at least 15 minutes for each treatment. The residual dichromate may amount to 0.005 mg., and is detected and measured by a delicate pink color reaction with alpha, delta diphenyl-carbohydrazide.

J. S. H.

CLEAN AIR, AN ACHIEVABLE ASSET.[1]

BY

H. B. MELLER,[2]

Mellon Institute of Industrial Research.

After two decades of pioneer research into the causes of and the remedies for city air pollution, Mellon Institute of Industrial Research is more strongly than ever of the opinion that clean air is not only a desirable but also an achievable asset. This statement is made in full appreciation of prevailing economic conditions and in the belief that these are preliminary to a period of extensive industrial, transportation, and domestic facility replacements. In this period, utmost advantage should be taken of the chance to promote the principle of reasonable smokelessness and dustlessness. Evidence justifies the conclusion that immediate recognition of the significance of hygienically pure air is fundamental to the financial and societal success of the general rehabilitation program. Especially does this apply to the housing and the slum clearance contemplated by the Director of Housing of the Federal Emergency Administration of Public Works as the major item in the movement for permanent national recovery. The Institute's air pollution specialists are convinced that satisfactory realization of the opportunity offered to advance public health through the rehousing of millions of urban families is inseparably connected with the abatement of excess atmospheric pollution, of a practically preventable type, common to centers of population.

In support of this observation, attention is directed to the fact that an incessant rain of soot, tar, ash, oil, and acid compounds has contributed weightedly to the burial of many of the tens of billions of dollars unprofitably invested in city realty and to the development of blighted areas whose re-

[1] Presented at the Stated Meeting held Wednesday, November 15, 1933.

[2] Head, Air Pollution Investigation, Mellon Institute of Industrial Research, Pittsburgh, Pa.

organization is essential to the solvency of many municipalities. A communication from the Director of Housing, at Washington, indicates his belief in the relevancy of pure air to the success of the housing projects.

It appears to be of timely importance that there should be an evaluation of attempts made to curb preventable air pollution. A critical review will prove the necessity for integration of control efforts on the part of governmental agencies, the medical profession, scientific research workers, engineers, architects, civic organizations, business executives, and citizens generally.

It is a pleasure to recall that, in the early stages of the country's studies of smoke effects and restrictive measures, The Franklin Institute was active in developing the scientific aspects involved. THE JOURNAL OF THE FRANKLIN INSTITUTE contains extended discussions of the basic problems associated with atmospheric contamination. These contributions to national thought were influential in stimulating serious consideration of scientific means and methods for abatement of the nuisance. It is gratifying to find, many years later, that the members of the Institute have a continued interest in the problem.

The relevancy of clean air, and especially of hygienically pure air, to the future of many American cities was never more clearly indicated. Prompt realization of the importance of this observation and action based upon such apprehension are called for, since air pollution from smoke has spread to many places heretofore historically free from it.

Among the cities in which there has been agitation against the smoke nuisance are New York, Philadelphia, Buffalo, Boston, Baltimore, and Washington. According to very recent reports, the society resort, Newport, is getting its first highly irritating breath of air unduly contaminated by products of combustion. In common with many other communities, especially in the New England states, Newport is complaining about a nuisance with which formerly it was unacquainted, and which in large part is due to a failure properly to regulate the use of fuels and fuel-burning equipment.

Damage by smoke products is an old story in industrial cities where the principal fuel has been bituminous coal, but in

these cities complaints did not bring extensive action until the first decade of the present century. Ordinances of one sort or another have been passed in more than 125 cities of 30,000 or more population. In most of the municipalities where considered attempts have been made to curb atmospheric contamination, conditions generally have improved as regards the emission of visible smoke, but regulation lacks in the control of cinders and ash from soft coal, oily soot from the burning of oil, and sulfur gases. In those cities, also, the people are demanding a wider and stricter measure of regulation.

For the decrease in the volume of dense smoke, much of the credit justly is given to the large fuel consumers who have engaged successfully in research to secure increased efficiency in combustion, and to manufacturers of fuel-burning equipment and producers and processers of fuel who have worked to the same end. Public demand has proved potent in the development of municipal regulations, which have resulted in an increase in the use of smokeless fuels and have supplied much expert advice in the selection, installation and operation of improved appliances. And, of course, the contribution made by electrification of railroads cannot be overlooked.

The smoke nuisance, however, has been considered mainly from the æsthetic and economic standpoints.

There is an instinctive psychological rebellion against smoke and dust that ranges all the way from protests by the ordinary citizen to the cry of despair raised by architects and artists who find their ablest efforts in ornamentation and decorative effect obliterated by concentrated grime. It is a matter of common observation that a smoke pall takes the sparkle out of sunshine and tends to make the world drab and gray. A heavy smoke pall creates an unnatural ceiling. And only recently the pupils of a school voted unanimously for the removal of frosted glass from their windows, saying they felt as if they were in jail. Each of these conditions suggests unwarranted restriction of freedom—a form of bondage.

In the broad field of economics, especially as it is related to industry and trade, investigations of the sources, effects and control of impurities in mill, factory and store air are found to be extensive and growing. Some of the conclusions reached

there have led, or will lead, to radical changes in the use of materials and in working conditions, manufacturing processes and merchandising methods. Portions of the more recent scientific findings made by industrial and commercial enterprises on their own account are being applied gradually to home life, largely through purchase of appliances and newly designed materials. But there is practically no evidence that these privately-financed findings have been written into city ordinances which cover outdoor atmospheric conditions. The cities are being outdistanced by private establishments in this phase of progress.

The question of possible relationships between atmospheric impurity and human health has been receiving the occasional attention of medical science for many years. As reliable data have been gathered and correlated, the case that men of medicine are building against excessive air pollution has grown stronger. Investigations continue and are broadening, but many of the findings still are inconclusive. Individual expression of belief by physicians, however, is taking on a more positive tone. One nationally recognized medical authority, within the month, has said, in a private communication: "Variations in deaths from respiratory diseases in different parts of the country might, to an appreciable extent at least, be an index of the effects of atmospheric pollution."

NATURE OF AIR POLLUTION.

The contaminants of air are solid, liquid, and gaseous in character. They include oil, tar, particles of carbon and ash, and sulfur and other gases, from the combustion of fuel; dusts, metallic particles, and gases from industrial processes; brick, stone, and metallic particles from buildings and streets; various organic materials, such as particles of vegetal origin; and many others. It is the products of combustion, however, with which we are chiefly concerned, as in the average community they are the principal pollutants.

Fuels and Their Composition.

The fuels commonly used are coal (anthracite, semi-bituminous, and bituminous), coke, oil, and gas (natural and manufactured). Considered as a group, these fuels are com-

posed of carbon, hydrogen, sulfur, oxygen, nitrogen, and ash; the first three of these are combustible.

Carbon occurs as fixed carbon and in combination with hydrogen in the hydrocarbons or volatile matter. As a rule, the amount of soot, tar, and smoke that may be produced from the incomplete burning of fuel depends upon the amount of volatile matter in that fuel. But volatile matter itself varies in composition from that which is not difficult of combustion in an ordinary furnace without the production of visible smoke, to that which must be burned in carefully constructed and operated furnaces if dense smoke is to be prevented.

Anthracite and coke contain very small amounts of volatile matter, and therefore are inherently smokeless. Semi-bituminous and bituminous coals have smoke-making possibilities in proportion to the amount of organic matter that they contain. Oil and gas, the "all-volatile" fuels, must be used in specially designed burners. Recognition of this observation about the great care to be taken in the burning of fuel oil is contained in a very recent pronouncement by the General Electric Company, wherein explanation is made of the false economy and improper results that follow the use of conversion burners.

All the fuels mentioned, except some of the natural gas, have small amounts of sulfur, and the solid fuels contain ash.

Combustion and Its Products.

Theoretically, the process of combustion is simple, being a chemical union of the burnable material of a fuel with oxygen from air, the combination resulting in the development of heat. Many difficulties develop in practice, however, and it is in overcoming them that care is required in the design, construction and operation of fuel-burning equipment. The number and nature of the difficulties vary considerably with the composition and fineness of the fuel, the type of furnace, the method of firing, the supply of draft, the amount and composition of impurities in the fuel, and the variable demands for heat or power.

If combustion is complete, the gases leaving the stack will be carbon dioxide and water vapor, plus sulfur-containing compounds; and with solid fuels there will be such particles of

carbon and ash as are taken out by reason of the draft. Only a haze will be visible coming from the stack; so far as visible smoke is concerned, the stack emission is unobjectionable.

If combustion is incomplete, there will be, in addition, tarry matter and finely divided carbon—in other words, visible smoke.

SMOKE NUISANCE NOT A RECENT DEVELOPMENT.

The smoke nuisance is as old as the use of high volatile coal for fuel. In America, one of the earliest commentators was your own Benjamin Franklin. The suggestions he advanced were as sound as if made in the light of the knowledge of the twentieth century. As cities increased in number and size, and as many of them became centers of large industries, enormous quantities of bituminous coal were burned. This fuel was in most places so cheap that combustion efficiency was not a factor. The smoke and dust in such areas of population came to be considered a necessary accompaniment of modern city life. The people became, and to a great extent still are, unnecessarily tolerant.

Prominent among the industrial cities notorious for smoke was Pittsburgh. Periodically, protests were raised, city ordinances were passed, modified and abolished. None of these amounted to more than a gesture. Back of all was a lack of knowlege of the effects of the products of combustion and the mistaken idea that "smoke is a sign of prosperity." The individual sufferer received scant attention until the very beginning of the present century.

MELLON INSTITUTE'S STUDIES.

In 1911, Mellon Institute of Industrial Research entered upon a comprehensive investigation of the causes and effects of urban air pollution. The findings of three years' study were reported in nine bulletins, which still are considered authoritative.

In addition to making careful studies of hundreds of plants, from the large industrial furnaces and boilers, and the railroad locomotives, to domestic heating furnaces, measurements were made to determine the amount of sootfall in the city. While this precipitation varied from several hundred

tons per square mile per year in the cleaner districts to well over two thousand tons in the dirtiest districts, the average for the city was approximately one thousand tons per square mile per year. Representative samples of this material were analyzed and reported to average 1 per cent. tar, 31 per cent. combustible other than tar, 43 per cent. ash, and 25 per cent. iron oxide.

Effects of Smoke.

The major part of the work had to do with effects of these pollutants; in this not only visible smoke, but all the products of combustion, whether solid or gaseous, visible or invisible, were considered as to their separate or collective action. Most of the findings given in these bulletins are now generally understood; it will be sufficient, therefore, to treat them very briefly at this time.

The effects reported included the griming of stone and metalwork by carbon and tar; the destructive action of sulfur acids upon stone, especially when the acids are accompanied by tar; the corrosive effects of acids upon metals; the deterioration of protective coatings; the soiling and damaging of interior decorations and of fabrics; and the retardation of the growth of vegetation.

It was shown that smoke aids in the formation and prolongation of fogs; that it increases their density and therefore their opacity to sunlight, particularly in the shorter wavelengths. In the absence of fog, smoke and dust in the atmosphere reduce the intensity of daylight, as shown by studies made in Pittsburgh by Mellon Institute, and by the U. S. Public Health Service in New York and Baltimore, where the average reduction attributed to smoke was over twenty per cent.

The principal pathological effects, it was stated, are due to inhalation of solid particles, and to the depletion of sunshine, especially in the ultraviolet region. Medical specialists have informed us that inspired air-borne impurities irritate the sensitive membranes of the eyes, nose, throat and lungs, and thus aggravate or cause various maladies of those organs, or increase their susceptibility to acute diseases of the respiratory tract. These pollutants also enter the gastro-intestinal tract and may induce systemic poisoning.

The Economic Cost of Smoke.

Estimates were made, based on the best information attainable, of the money loss due to smoke. This was placed, for the Pittsburgh of two decades ago, at about $15.00 per capita per year. In surveys made in other cities—as New York, Chicago, Salt Lake City, Boston, Baltimore, etc.—the estimates varied from $10.00 to more than $30.00 per person per year. We can express the opinion that all these approximations are far too low. One of the greatest needs in the field of smoke and dust control is a thoroughgoing economic investigation.

Municipal Regulation.

While this early research was being carried on at Mellon Institute, there was in preparation a proposal for an ordinance that should curb, as far as practicable, the production and emission of deleterious products of combustion in Pittsburgh. As first contemplated, it aimed to prohibit dense smoke and to regulate to a reasonable degree the discharge of cinder and fly ash into the atmosphere; and it recommended no exemptions. Because of the opposition that it was thought might be encountered, the committee was advised to forget about dust, and to exempt private homes and apartment houses containing less than six apartments.

The ordinance as passed, therefore, prohibited opaque smoke—that is to say, smoke of such density that it was impossible to see through a column of it at the point of emission from the stack—for periods aggregating more than two minutes in any fifteen consecutive minutes. Any amount of smoke less dense than this was, and is, permitted; private homes and small apartment houses were, and are, exempt from any regulation; with no legal attempt to control cinders, ash, or noxious gases.

The Pittsburgh ordinance is no exception in this respect. It is mentioned because it is typical, and in fact has been the basis for much of the anti-smoke legislation passed in other cities. So, also, the story of Mellon Institute's studies of air pollution during the period since 1911 parallels the advance in knowledge of effects of pollutants and of development of methods for their control. That must be my excuse for following so closely in this paper the work done in Pittsburgh.

A Bureau of Smoke Regulation was set up in the Department of Health, and, for a time, rapid progress was made in cleaning up. Honest effort on the part of the city officials charged with enforcement and cooperation by plant owners and operators brought what seemed to be excellent results.

MELLON INSTITUTE'S SECOND SURVEY.

In 1923, it was decided to ascertain the results of ten years' enforcement of the ordinance. Accordingly, using the same stations and methods as in 1912–13, sootfall was collected over a period of a year. It was found that the percentage of tarry matter had been reduced more than two-thirds, indicating successful enforcement of the law. At the same time, the total amount of solids had increased nearly forty per cent. This was explainable largely by the fact that some of the measures taken to prevent dense smoke resulted in the discharge of more fixed carbon and ash.

It was plain that it was necessary to inaugurate a campaign to clean up the dust. It was thought that, for the initial part of such work, sufficient facts were in hand. Through the city's Bureau of Smoke Regulation, manufacturers of fuel-burning equipment were impressed with the importance of making improvements in design which would tend to reduce the amount of solids carried to the stack. Office regulations were strengthened. Stoker manufacturers were asked to make units for the smaller plants. The development of dust separators, especially in medium and small sizes, was urged. Better preparation of some fuels was advocated. These matters were brought to the attention of engineers through the medium of papers read at meetings of their societies and published in technical journals. It can be said from this experience that manufacturers are ready to meet requirements for practically smokeless combustion and reasonable separation of dust whenever demand is made.

In the meantime, much was being written about the effects of dust particles so small that most of them would not normally fall to the ground. And the study of ultraviolet radiation assumed proportions that indicated the need to determine the amount that was being received from the sun in different seasons and under different atmospheric conditions.

THE THIRD SURVEY.

So in January, 1929, the investigation was resumed.

Precipitated Solids.—A third sootfall survey was made, to compare with the two previous ones. It was found that the total amount of sootfall had decreased to nearly the figure for 1912–13—in other words, the ground unwittingly lost in the first ten years had been regained—with a still further decrease in the amount of dense smoke prohibited by law. An interesting new fact shown was that the large increase in the number of automobiles had brought a corresponding increment in the amount of tarry matter collected with the precipitated solids.

Suspended Solids.—Studies were made to determine numbers and sizes of solids in suspension in the atmosphere in Pittsburgh.

Samples of air were taken by methods similar to those used in England, where much basic work of this character has been done, and where Dr. J. S. Owens developed his automatic filter and his jet dust counter.

The automatic filter samples the air periodically (usually at intervals of twelve or fifteen minutes). Essentially, the apparatus consists of a water chamber which fills slowly and empties automatically; a revolving disk carrying a standard filter paper marked to indicate the twenty-four hours of the day, and a clock mechanism. When the water chamber has filled and the discharge valve opens to allow the water to run out, the vacuum at the top of the chamber pulls open a valve in a small pipe which reaches upward to the filter paper. The revolving disk stops temporarily and two liters of air are filtered through the paper. The density of the spot caused by the solids filtered out is considered an indication of the amount of such solids in the atmosphere. Obviously, the shade of color left on the paper is dependent upon the proportion of black solids only in the sample.

The jet dust counter was designed for the purpose of securing small samples of microscopic dust in air. It consists of a hand pump of 50 c.c. capacity, at right angles to which are the head containing the precipitation chamber and a tube which is the damping chamber. In the damping chamber is a blotter, which is kept moist when the instrument is in use. A microscope cover glass is placed in the precipitation chamber.

Air is drawn through the damping tube, where it picks up moisture; it passes at high velocity through a slit .1 mm. wide by 3 mm. long to the precipitation chamber, from which it is pulled to the cylinder of the pump and exhausted. The reduction in velocity and change of direction of the air stream after it goes through the slit cause all contained solids to precipitate on the cover glass. The cover glass is then mounted on a slide for examination under a microscope. At 1000 diameters it is possible to see particles as small as 0.2 micron, and under good conditions even 0.1 micron. Of course, larger solid particles are excluded because of the narrowness of the orifice.

A dust counter developed by E. Vernon Hill was used to some extent. Solids from air samples are precipitated on a grease-coated glass. Integral with the instrument is a microscope (80 diameters), so that the particles may be counted without necessitating any special preparation. The orifice will pass larger particles than can be collected with the Owens counter, and the Hill counter is valuable for the study thereof. It has a distinct advantage in that it has a piston speed control on the pump, insuring uniformity in sampling and thus eliminating personal errors.

An impinger type of sampler, developed and used by the U. S. Bureau of Mines and U. S. Public Health Service in connection with work in the field of industrial dusts, was tried but not used regularly.

Such methods indicate conditions at specific times and places, and may or may not represent an average either at the place or for a larger area. Spot sampling may give an erroneous impression, and this eventuality was to be avoided, if possible. It was desired to secure continuous readings which would give a measure of pollution, and variations due to smoke, changes in wind velocity and direction, etc., for a considerable area. It was believed that a measure of the obstruction of light from a standard source, with photoelectric cells as receivers, would answer the purpose, but no suitable apparatus was available. With the assistance of Dr. E. D. Wilson, of the research department of the Westinghouse Electric and Manufacturing Company, a differential circuit was devised to nullify the effects of any changes in light except from a standard lamp,

so that variations in the energy output from the receiver would be indicative of obstruction of light due to solids and moisture in the intervening air. The standard lamp was placed at a distance of 3000 feet, and the output from the receiver was recorded on a Leeds and Northrup recording potentiometer.

The importance of such dust studies will be evident when it is remembered that it is the smaller particles, those that tend to remain in suspension indefinitely, that irritate the membranes of the nose, throat, and lungs, and that lodge in the lungs, with possible consequent damage. The number of such particles in the air breathed varies between wide limits; crossing and recrossing the danger line, according to rate of supply and atmospheric conditions.

Ultraviolet Radiation.—These particles, as well as the larger ones, help to build up fogs, and also play a large part in screening out sunlight, particularly in the ultraviolet region. The recent advances in the study of vitamins—in particular vitamin *D*, which comes naturally from the action of ultraviolet light on the skin—indicated the importance of studying solar ultraviolet radiation. It was considered most desirable to secure continuous records, but, again, there was no satisfactory apparatus available.

At this time it was learned that Dr. H. C. Rentschler, director of research of the Westinghouse Lamp Company, was engaged in developing a method of measuring ultraviolet radiation shorter than 3350A by the use of a uranium photocell. Dr. Rentschler willingly demonstrated this instrument, which was intended to be used by physicians in measuring the dosage of ultraviolet radiation from artificial lamps. He was asked to make modifications necessary to adapt his meter to use in open sunlight, and two instruments so modified were loaned to us by the Westinghouse Lamp Company. With these, continuous records were made of natural ultraviolet light received in Pittsburgh over a period of more than a year and a half, and some of the results were published. For the period studied, it was shown, among other things, that the ultraviolet radiation received in June was about six times as much as that received in December; that the intensity at noon on a clear day in June was two and a half times that at noon on a

clear day in December; and that even a light "smoke blanket" materially reduced the intensity of the radiation. Comparisons were made from time to time with chemical methods of measuring ultraviolet radiation.

From the Pittsburgh station of the U. S. Weather Bureau there were available records of total solar radiation—ultraviolet, visible and infrared—as well as of temperatures, relative humidities, rainfall, wind directions and velocities. These were used for correlation with the information gathered at the Mellon Institute station.

Improved Instrumentation and Procedure.—There are, I think, excellent opportunities for strictly physical research in evolving superior instruments for collecting, counting, and determining the hardness or irritational property of dust particles. In our work of the past, we have employed devices used elsewhere, in order to secure comparative data. It is plain to us, however, that when time permits and facilities are available, these contrivances can be improved through additional investigation. Just at present, Mellon Institute is carrying on studies relating to silicosis, in collaboration with several companies and governmental bureaus; and it is hoped that these researches will contribute toward definite advances in instrumentation and procedure.

Similarly, there is need for simpler precise methods of simultaneously measuring and recording by automatic means the various regions of the spectrum—the short ultraviolet, the longer ultraviolet, the visible and the infrared. Investigation along this line is under way at Mellon Institute and elsewhere.

Sulfur Dioxide.—Uncertainty as to the amount of sulfur dioxide in Pittsburgh air led us, during 1932, to make 280 determinations on 224 days, to ascertain the facts. The average concentration of sulfur dioxide was found to be 0.14 part per million parts of air. The highest concentration occurred on November 28th during a fog, when it reached 1.1 parts per million.

Carbon Monoxide.—Another factor in air pollution about which few authoritative data were available was the concentration of carbon monoxide from automobile exhausts at busy traffic intersections. With a carbon monoxide recorder of the Pittsburgh Experiment Station of the U. S. Bureau of Mines,

and with the coöperation of the City's Departments of Health and Safety, a twelve months' study was made at some of the busiest corners downtown. The concentration at the curb did not reach the point where the first symptoms of carbon monoxide poisoning might be expected. Conditions in several parking garages were studied; in one, in particular, poisonous concentrations were found at times, and remedies suggested and applied. In the Liberty Tubes, which were included in the study, concentrations considered dangerous were noted at times when traffic was jammed. A report was submitted to the County Commissioners (at their request), and nearly all the recommendations made have been followed.

Throughout the years we have maintained a constructive attitude, looking toward the most effectual minimization of atmospheric contaminants. Our surveys have constituted the fact-finding bases for our planning.

Recent Dust Data.

In an earlier paragraph reference was made to the failure of municipal air pollution regulations to reflect the more recent findings of research scientists employed by industry, especially those who are intent upon the control of dust in connection with factory processes and air conditioning. These findings are based on data gathered in large part in the last several years. Not all the data have been correlated, even for industrial purposes. Some of the conclusions which appear to be the most important have been announced only within recent months. It must be expected that some time will elapse before a general study of the freshly developed facts can be completed.

What Concentrations of Which Dusts Are Injurious?—These data indicate that there is what may be termed a "safe load" of air pollutants, viewed from the health angle. In mines and factories it is found that, up to certain concentrations, non-toxic dust appears to be relatively uninjurious to a worker, but that above those concentrations permanent injury may be expected to result. The research into outdoor air pollution is being directed toward the determination of the amounts and kinds of contaminants that can be breathed with safety.

Among the products of combustion of fuel common to city air are silica and carbon. It happens that most of the research recently done has been directed toward the harm from silicon compounds breathed into the lungs. In the same period there have been some assertions to the effect that carbon particles may not be dangerous to health. I cannot support that conjecture. Dr. Samuel R. Haythorn, nationally recognized pathologist, in a private communication, points out some of the effects of carbon which he has seen. Other medical specialists who have been associated in the past with Mellon Institute's studies—notably Drs. Oskar Klotz and Wm. Charles White—are in agreement with Dr. Haythorn. It is essential that determinations be made of the relative amounts of carbon and other deposits, from various recognized sources of pollution, as they are found in the dried tissues of typical lungs. This is the only way in which anthracosis, silicosis and the various forms of lung fibrosis may be indisputably separated.

On the question of how much silica can be permanently harbored in the human lung without apparent harm, Dr. William D. McNally has found that "the normal lung contains 1.13 milligrams of silicon dioxide per gram of dried lung tissue," and that "any lung containing over 2 milligrams of silicon dioxide per gram of dried lung tissue indicates undue exposure to dusty atmosphere."

When attempt is made to draw a lesson from these findings and apply it to the life of the ordinary city dweller, it is proper to ask if the silica content of city dust exists in concentrations that amount to "undue exposure." On this point, Dr. McNally cites the results of investigations of the lungs of several persons of varied occupations who died of various diseases. He gives eight instances where the amounts of silica were indicated to be harmful. Of these, two were houseworkers, one an automobile painter, and another a man who worked part time as a farmer and part time in a steel mill. The latter's lungs showed 7.06 milligrams of silica per gram of dried lung tissue. The figure for a building worker was 2.37 milligrams, and for a coke shoveler in a coal yard, 9.75 milligrams. This latter is more than eight times the amount stated by Dr. McNally to be normal.

The facts here cited indicated very strongly that "undue exposure to a dusty atmosphere" was encountered in some homes and in some occupations not usually considered "dusty."

The particular data may be too scant to warrant the drawing of inferences as to the extent of the outdoor atmospheric pollution in which these people lived and worked, but they do suggest that research be directed toward determining the dust content of the air of cities where there is a strong suspicion that concentrations may be above the danger line. The prevalence of acute respiratory diseases probably will be useful in indicating the municipalities where research is most urgently needed.

During the current half-year there have been made available other pertinent data tending to show the rate at which silica operates to create disability. According to a statement by Dr. R. R. Sayers of the U. S. Public Health Service, it appears that the age at which workers took employment in one dusty occupation was a large factor in determining the length of time required for the development of the first stage of one form of dust disease. For workers starting under 40 years of age, the average time was 13 years; over 40, an average of 7.8 years. This fact indicates either that age brings a progressive decrease in the body's capacity to resist the effects of silica dust or that a build-up of this dust has occurred in the lungs. Whether the natural filter may be said to have lost about 40 per cent. of its effectiveness at around 45 to 50 years is for medical research to determine.

At the present stage of the investigation into the relevancy of outdoor dust to the effectiveness of the human body's energy-producing mechanism, it is too early to do much more than to designate promising lines of inquiry and to indicate objectives. For instance, it is well known that science has been unable to make any appreciable progress in lowering the death rate above the age of 55 years. Here is a field for research into any dust effects. Should investigation reveal that the accumulation of dust in the lungs is explanatory of some otherwise inexplicable human failures in the fifties and sixties, may not light also be thrown on the effects of outdoor air

pollutants in creating partial bodily disabilities of an incurable sort during, say, the thirties and forties?

The suggestion is that dust may be shown by research to be a sizeable agent in cutting down the capacity of a considerable percentage of workers, so that those affected are unable to generate effective energy sufficient to maintain steady and profitable productiveness. It may be observed that a loss in human efficiency attributable to dust in the lungs is probably permanent, whereas disability due to some of the other kinds of common illnesses may be only temporary. In the latter case, medical treatment might restore a human machine to approximately full power. Unless similar prospect of practically complete recovery exists for persons who acquire an excess burden of inspired dust, it would appear that necessity for guarding against dangerous concentrations of outdoor air pollutants calls for research in the name of public health.

When we know the "safe load" of these and other dusts, either separately or in combination, that the human lung can carry, and when we have progressed further in the study of the effects of these pollutants in screening out the natural ultraviolet radiation, it would seem theoretically possible to translate this knowledge into terms of the average amounts of such materials that may be permitted in ordinary street air. That being determined, the next step would be to delimit the amount that would be allowed at the source of smoke and/or dust production.

Outdoor and Indoor Air Conditioning Related.—The restoration of hygienic purity to outdoor air and the conditioning of the air supply of buildings have many problems in common. At the inception of indoor air conditioning research, there was scant understanding of the role that microscopic dust plays in harming health and property. The story of its development is one of continuous pursuit of knowledge concerning the origin and nature of dust and the invention and improvement of methods for its control.

For the present, the air conditioning industry is proceeding on the assumption that dust which lodges in the lung and may there cause damage ranges in size from 6 microns to 0.4 micron in greatest diameter. This important and growing industry has encountered so many difficulties because of aggravated

outdoor air pollution that it is looking hopefully toward all public movements for the cleanup of urban atmosphere.

Unnecessary to Remove All Solids.—The task which confronts us is one that must be performed by the coöperative effort of the physician, the chemist, the physicist, and the engineer. We see no necessity for attempting to screen out all the pollutants. From the health viewpoint, the problem as it is now posed for us is to prevent the occurrence of concentrations above the danger line. We can rely upon the natural filter with which each of us is equipped to handle the atmospheric dust load, provided that load is kept within the margin of safety. From the viewpoint of the economist, who is chiefly concerned with effects other than the hygienic, the limit is reached only when the cost exceeds the return.

Indicated Remedial Procedures.

The simplest answer to the question of elimination of tar and finely divided carbon particles that result from the incomplete burning of certain fuels will be found in complete combustion. In industrial processes which permit the escape of these and other combustible products, provision can be made to render them inoffensive by burning.

To bring ash and industrial dust concentrations to the safe level, separation within the plant will be necessary.

The elimination or neutralization of the sulfur acids is another problem that as yet is not satisfactorily solved.

It is clear that effective legislation must provide for the exercise of control over not only plants that burn fuel, but plants that produce harmful quantities of dust. Smoke abatement bureaus must be expanded into bureaus of air hygiene, with sufficient support to insure effective work. And the geographical limits must be extended to include the whole of a smoke-producing area—not stopped at the city line.

The large number and wide distribution of inquiries reaching the air pollution investigation at Mellon Institute cause us to feel that we are entering an era of replanning. The answer to requests for information and guidance will be found in discussions such as the one we are holding here this evening.

It is groups such as the present meeting that are being looked to for critical thought and constructive action.

The great variety of suggestions that have been made and will be made for atmospheric betterment must be evaluated scientifically if we are to escape mistakes of the type of those made in the past. These suggestions include extension of large central heating and power plants, the piping of pulverized solid fuels from the mines, generation of electricity or gasification of coal at the mines, changes in locomotive fuel, and such.

Cities which have available abundant supplies of smokeless fuels, such as electricity, gas, anthracite, and coke, can make the greatest immediate progress by expanding the use of these fuels.

Science has benefited public health to a vast extent by improving our water supplies. Science has also greatly elevated the quality of foods, drugs, and the comforts of life. There is ample evidence of the need for serious scientific attention to the hygienic control of atmospheric contamination, especially in industrial cities. It is gratifying to observe that our pioneer work at Mellon Institute is bearing fruit and is leading to thoughtful consideration by medical specialists, many scientists, Federal and State authorities, and other public-spirited citizens in various sections of the country. There is indeed an opportunity for a widespread contribution to an era of more gracious living, upon which we may even now be preparing to enter.

LIST OF JOURNAL CONTRIBUTIONS OF THE MELLON INSTITUTE AIR POLLUTION INVESTIGATION, 1924–1933.

Reprints are available to interested persons.

"Economy through Smoke Abatement," by H. B. Meller. *Ind. Eng. Chem.*, **16** (1924), 1049–1051; *Pittsburgh First*, **6** (1924), No. 27, 1–2.

"Smoke Abatement," by H. B. Meller. *Combustion*, **11** (1924), 217–219.

"Smoke Abatement an Economic Problem," by H. B. Meller. *Buildings and Building Management*, **25** (1925), No. 7, 29–34.

"Air Pollution in Pittsburgh," by H. B. Meller. *Pittsburgh Med. Bul.*, **14** (1925), No. 27, 14–20.

"How Cities Can Control the Smoke Nuisance," by H. B. Meller. *Nat. Mun. Review*, **15** (1926) No. 5, 270–276.

"Smoke Abatement, Its Effects and Its Limitations," by H. B. Meller. *Mech. Eng.*, **48** (1926), 1275–1283.

"Damage Due to Smoke," by H. B. Meller. *Trans. Am. Soc. Mech. Eng., Fuels and Steam Power Section*, **50** (1928), No. 33, 213–221.

"The Capnometer, an Instrument for the Measurement of Air Pollution," by H. B. Meller. *Science*, n. s. **71** (1930), 344–345.

"Smoke Abatement in U. S. A.," by H. B. Meller. *J. Nat. Smoke Abatement Soc.*, 1 (1930), No. 3, 75, 77, 79.
"Air Pollution from the Engineer's Standpoint," by H. B. Meller. *Heating, Piping and Air Conditioning*, 3 (1931) No. 1, 70–75.
"The Facts about Our Soot and Dust," by H. B. Meller. *Pittsburgh Record*, 5 (1931), No. 5, 37–44.
"Some Hygienic Aspects of the Air Pollution Problem," by H. B. Meller. *Pittsburgh Med. Bul.*, 20 (1931), 793–800.
"The Trend of Smoke Abatement," by H. B. Meller. *Combustion*, 3 (1931), No. 4, 9.
"What is Ahead in Smoke Abatement," by H. B. Meller. *Chem. Met. Eng.*, 38 (1931), 511–512.
"Where the Soot Falls," by H. B. Meller. *Greater Pittsburgh*, 12 (1931) No. 1, 17–18.
"Carbon Monoxide Survey in Liberty Tubes, Pittsburgh," by W. A. Hamor, H. B. Meller and others. *J. Ind. Hygiene*, 14 (1932) 295–300.
"Air Pollution," by H. B. Meller. *Greater Pittsburgh*, 12 (1932), No. 11, 23, 28.
"Studies of Ultraviolet in Daylight," by H. B. Meller, S. G. Hibben and Mary E. Warga. *Trans. Illum. Eng. Soc.*, 27 (1932), No. 1, 64–81.
"City Air Pollution and Its Control in a Period of Industrial Depression," by H. B. Meller. *The Aerologist*, 9 (1933), No. 2, 5–7, 29; No. 3, 9–11.
"Effects of Air Contaminants on the Natural Light of Cities," by H. B. Meller and Mary E. Warga. *Amer. Jour. Pub. Health*, 23 (1933), No. 3, 217–224.
"Sulfur Dioxide in Pittsburgh Air," by Carlisle Schade. *J. Ind. Hygiene*, 15 (1933), No. 3.
"Warring on City Smoke and Dust," by H. B. Meller. *Progress*, 1 (1933), No. 5, 11, 61.
"Smoke an Areal as well as an Aerial Problem," by H. B. Meller. Abstract in *The American City*, 48 (1933), No. 8, 61.
"Killed by Smog," by L. B. Sisson. *The Literary Digest*, April 5 (1933), 20.
"Modern Plan for a Community Campaign against Air Pollution," by H. B. Meller. *Amer. Jour. Med. Sciences*, 186 (1933), No. 2, 157–164.
"Vegetation Rescued from Injury by Smoke," by L. B. Sisson. *The American Home*, December (1933), 52.

A METHOD OF COMPUTING DIFFERENTIAL CORRECTIONS FOR A TRAJECTORY.

BY

ALBERT WERTHEIMER,

Navy Department, Washington, D. C.

1. INTRODUCTION.

In preparing Range Tables for anti-aircraft guns, the trajectories are computed for a given initial velocity and assumed standards of air density, weight of projectile, etc. The table then gives for various angles of elevation, the coordinates x and y at any time t. The trajectories are computed by the method of numerical integration developed by Moulton.[1]

Besides the standard trajectories, however, it is also necessary to determine the variations in x and y at any time t, due to variations in initial conditions as velocity, air density, etc. There are two distinct methods of obtaining these variations. We can either compute independently a trajectory corresponding to the varied initial conditions, or we can develop some method by which for any given variations in initial conditions, the variations in x and y are obtained as functions of the elements of the standard trajectory.

The first method has the disadvantage that any error in the computation of the trajectory which may be negligible compared to the elements of the trajectory may be very large relative to the differential variations. Also the use of the second method is as a rule economical of labor.

In the method developed by Moulton [2] all second order terms of the differential are neglected, and hence this method can be applied only to very small variations. However, the chief objection to the method is that it requires again the solution of a system of differential equations by numerical integration, which is a very laborious process.

[1] F. R. Moulton, "New Methods in Exterior Ballistics," 1926.

[2] Loc. cit., Chapter IV, pp. 80–141.

Sample Computation.

Standard Trajectory: $V = 731.5$ m.s., $\varphi = 30°$, $C = 3.60$,
$\Delta V = -15$ m.s., $\Delta\varphi = 0$, $\Delta C = 0$.

		Time Intervals					
		0–½ $t = ½$	½–1 $t = ½$	1–1½ $t = ½$	1½–2 $t = ½$	2–3 $t = 1$	3–4 $t = 1$
	E_0	0.07768	0.07457	0.07168	0.06902	0.06646	0.06177
	E_t	0.07456	0.07168	0.06900	0.06645	0.06180	0.05736
	E_m	0.07612	0.07318	0.07034	0.06774	0.06413	0.05956
	ϵ_0	0.07858	0.07536	0.07244	0.06972	0.06713	0.06238
	ϵ_t	0.07536	0.07244	0.06972	0.06713	0.06238	0.05794
1	ϵ_m	0.07697	0.07390	0.07108	0.06842	0.06476	0.06016
	$d\epsilon_m$	−0.00085	−0.00072	−0.00074	−0.00068	−0.00063	−0.00060
2	$d\epsilon_m t$	−0.00042	−0.00036	−0.00037	−0.00034	−0.00063	−0.00060
	$\epsilon_m t$	0.0385	0.0370	0.0355	0.0342	0.0648	0.0602
3	$e^{-\epsilon_m t}$	0.96223	0.96368	0.96512	0.96638	0.93725	0.94158
4	$1 - e^{-\epsilon_m t}$	0.03777	0.03632	0.03488	0.03362	0.06275	0.05842
5	$4.9\ t$	2.45	2.45	2.45	2.45	4.9	4.9
6	X_0'	620.5	597.3	575.9	556.0	537.5	504.2
	x_0'	633.5	609.6	587.5	567.0	547.9	513.6
7	dx_0'	−13.0	−12.3	−11.6	−11.0	−10.4	−9.4
8	Y_0'	358.2	340.0	323.0	307.0	291.9	264.3
	y_0'	365.8	347.2	329.8	313.5	298.1	269.9
9	dy_0'	−7.6	−7.2	−6.8	−6.5	−6.2	−5.6
10	-4×7	+0.49	+0.45	+0.40	+0.37	+0.65	+0.55
11	$-2 \times 3 \times 6$	+0.25	+0.22	+0.21	+0.18	+0.32	+0.28

Sample Computation—(Continued)

		Time Intervals					
		0–½ $t = \frac{1}{2}$	½–1 $t = \frac{1}{2}$	1–1½ $t = \frac{1}{2}$	1½–2 $t = \frac{1}{2}$	2–3 $t = 1$	3–4 $t = 1$
	$d\Delta x'$	+0.74	+0.67	+0.61	+0.55	+0.97	+0.83
	$\Delta x'$	−23.9	−22.1	−20.5	−19.1	−34.3	−30.0
	$\Delta X'$	−23.2	−21.4	−19.9	−18.5	−33.3	−29.2
	X_0'	620.5	597.3	575.9	556.0	537.5	504.2
	X_t'	597.3	575.9	556.0	537.5	504.2	475.0
12	-4×9	+0.29	+0.26	+0.23	+0.22	+0.39	+0.33
13	$-2 \times 3 \times 8$	+0.14	+0.12	+0.11	+0.10	+0.17	+0.15
14	$+2 \times 5$						
	$d\Delta y'$	+0.43	+0.38	+0.34	+0.32	+0.56	+0.48
	$\Delta y'$	−18.6	−17.4	−16.3	−15.4	−28.2	−25.3
	$\Delta Y'$	−18.2	−17.0	−16.0	−15.1	−27.6	−24.8
	Y_0'	358.2	340.0	323.0	307.0	291.9	264.3
	Y_t'	340.0	323.0	307.0	291.9	264.3	239.5
	$-10 \div 1$	−6.4	−6.1	−5.69	−5.41	−10.08	−9.12
	$+11 \times t/2$	+0.1	+0.1	+ .05	+ .04	+ .16	+ .14
	$d\Delta x$	−6.3	−6.0	−5.6	−5.4	−9.9	−9.0
	dx_0	0	−6.3	−12.3	−17.9	−23.3	−33.2
	dxt	−6.3	−12.3	−17.9	−23.3	−33.2	−42.2
	$-12 \div 1$	−3.78	−3.54	−3.33	−3.19	−6.01	−5.44
	$+13 \times t/2$	+ .03	+ .03	+ .03	+ .02	+ .08	+ .07
	$-14 \times t/3$						

Sample Computation—(Continued)

		Time Intervals					
		0–½ $t = ½$	½–1 $t = ½$	1–1½ $t = ½$	1½–2 $t = ½$	2–3 $t = 1$	3–4 $t = 1$
	$d\Delta y$	−3.8	−3.5	−3.3	−3.2	−5.9	−5.4
	dy_0	0	−3.8	−7.3	−10.6	−13.8	−19.7
15	dy_t	−3.8	−7.3	−10.6	−13.8	−19.7	−25.1
	$X_t'^2$	356767	331661	309136	288906	254218	225625
	Y_t'	115600	104329	94249	85206	69854	57360
	V_t^2	472367	435990	403385	374112	324072	282985
	v_t^2	492160	453924	419771	389057	336631	293697
16	dv_t^2	−19793	−17934	−16386	−14945	−12559	−10712
17	dlg_eG_T	$.0^5110$	$.0^5124$	$.0^5136$	$.0^5152$	$.0^5191$	$0^8.246$
	$.2172 \times 16 \times 17$	−0.0047	−0.0048	−0.0048	−0.0049	−0.0052	−0.0057
	$-0.0^445 \times 15$	+0.0002	+0.0003	+0.0005	+0.0006	+0.0009	+0.0011
	$dlg.i$	0	0	0	0	0	0
	$dlg\epsilon_t$	−0.0045	−0.0045	−0.0043	−0.0043	−0.0043	−0.0046
	$lg\epsilon_t$	8.8771	8.8599	8.8433	8.8269	8.7951	8.7629
	lgE_t	8.8726	8.8554	8.8390	8.8226	8.7908	8.7583
	E_t	0.07457	0.07168	0.06902	0.06646	0.06177	0.05732

Lower case letters refer to standard trajectory.
CAPITAL letters refer to varied trajectory.
Line 17 is from War Dept. Document No. 984 Table III

In this paper, differential formulæ are developed which require only the application of arithmetical processes to the elements computed for the standard trajectory, and thus offer a great saving in labor, especially when the variations due to various causes are to be computed for the same standard trajectory.

Elements of Standard Trajectory.

From War Dept. Document No. 984, page 18.

$V = 731.5$ m.s., $\varphi = 30°$, $C = 3.60$.

Time	x	x'	x''	ϵ	y''	y'	y
0	0	633.5	49.78	.07858	38.55	365.8	0
½	310.6	609.6	45.94	.07536	35.98	347.2	178.3
1	609.8	587.5	42.56	.07244	33.70	329.8	347.5
1½	898.3	567.0	39.53	.06972	31.66	313.5	508.3
2	1176.9	547.9	36.78	.06713	29.82	298.1	661.2
3	1707.3	513.6	32.04	.06238	26.65	269.9	944.9
4	2205.5	483.6	28.02	.05794	23.99	244.6	1201.9

Only those second order terms which are negligible over the entire trajectory even for fairly large variations, are neglected. All others are taken into account without making the formulæ too complicated. They are thus more accurate and can be safely applied to larger variations.

2. THE GENERAL METHOD OF THE DERIVATION OF THE FORMULÆ.

The fundamental equations, used for computing a trajectory are:

(1) $$x'' = -Ex',$$

(2) $$y'' = -Ey' - g,$$

where

$$x' = \frac{dx}{dt}, \qquad y' = \frac{dy}{dt}, \qquad x'' = \frac{d^2x}{dt^2}, \qquad y'' = \frac{d^2y}{dt^2}.$$

$$E = \frac{G(v)H(y)}{C}.$$

and

$G(v)$—a tabulated function of velocity,

$H(y)$—a tabulated function of altitude ($H(y) = 10^{-0^{4}15y}$),

C—the ballistic coefficient $\left(C = \frac{W}{id^2}\right)$.

If we should assume E to be constant, say E_m, for a small time interval t, we could integrate equations (1) and (2), and thus get the increments in x', y', x, and y for this interval.

However, the errors introduced would be considerable, and the method offers no advantage over the method of numerical integration.

But we can use these integrated expressions to get the differential corrections, as in this case we would be getting the difference of two quantities both of which contain errors of about the same magnitude, and hence it will represent nearly the true difference between these quantities. Applying these corrections to the computed increments of the standard trajectory, we will get the required increments for the varied trajectory.

3. THE SOLUTION OF THE DIFFERENTIAL EQUATIONS.

Notation:

Lower case letters refer to the std. Trajectory.
CAPITAL letters refer to the varied Trajectory.
Δ stands for the increment in the time interval t.
$d\Delta$ stands for the change in the increment Δ.

Assuming ϵ to have a constant value ϵ_m over the interval t, we have

$$x'' = -\epsilon_m x'.$$

Integrating, we have

$$x' = ke^{-\epsilon_m t}.$$

To determine k, we have

$$\text{for} \quad t = 0, \qquad x' = x'_0;$$

hence

$$x_t' = x_0' e^{-\epsilon_m t} \tag{3}$$

and

$$\Delta x' \equiv x_t' - x_0' = -x_0'(1 - e^{-\epsilon_m t}). \tag{4}$$

Integrating (3) we have

$$x_t = -\frac{x_0'}{\epsilon_m} e^{-\epsilon_m t} + k.$$

Here again for

$$t = 0, \qquad x = x_0,$$

hence,

$$k = x_0 + \frac{x_0'}{\epsilon_m},$$

so that

$$x_t = x_0 + \frac{x_0'}{\epsilon_m}(1 - e^{-\epsilon_m t}) \tag{5}$$

and

$$\Delta x \equiv x_t - x_0 = \frac{x_0'}{\epsilon_m}(1 - e^{-\epsilon_m t}). \tag{6}$$

For y' we have:

$$y'' + \epsilon_m y' = -g.$$

Integrating, we get

$$y' = -\frac{g}{\epsilon_m} + ke^{-\epsilon_m t}.$$

In this case

$$k = y_0' + \frac{g}{\epsilon_m};$$

hence

$$y_t' = y_0' e^{-\epsilon_m t} - \frac{g}{\epsilon_m}(1 - e^{-\epsilon_m t}) \tag{7}$$

and

$$\Delta y' \equiv y_t' - y_0' = -y_0'(1 - e^{-\epsilon_m t}) - \frac{g}{\epsilon_m}(1 - e^{-\epsilon_m t}). \tag{8}$$

Integrating (7) we get

$$y = -\frac{y_0'}{\epsilon_m} e^{-\epsilon_m t} - \frac{g}{\epsilon_m}\left\{ t + \frac{e^{-\epsilon_m t}}{\epsilon_m} \right\} + k.$$

Here

$$k = y_0 + \frac{y_0'}{\epsilon_m} + \frac{g}{\epsilon_m^2},$$

so that

$$y_t = y_0 + \frac{y_0'}{\epsilon_m}\{1 - e^{-\epsilon_m t}\} - \frac{gt}{\epsilon_m} + \frac{g}{\epsilon_m^2}\{1 - e^{-\epsilon_m t}\} \tag{9}$$

and

$$\Delta y \equiv y_t - y_0 = \frac{y_0'}{\epsilon_m}(1 - e^{-\epsilon_m t}) - \frac{gt}{\epsilon_m} + \frac{g}{\epsilon_m^2}(1 - e^{-\epsilon_m t}). \tag{10}$$

Collecting all formulæ, we have

$$\Delta x' = -x_0'(1 - e^{-\epsilon_m t}), \tag{4}$$

$$\Delta x = \frac{x_0'}{\epsilon_m}(1 - e^{-\epsilon_m t}), \tag{6}$$

$$\Delta y' = -y_0'(1 - e^{-\epsilon_m t}) - \frac{g}{\epsilon_m}(1 - e^{-\epsilon_m t}), \tag{8}$$

$$\Delta y = \frac{y_0'}{\epsilon_m}(1 - e^{-\epsilon_m t}) - \frac{gt}{\epsilon_m} + \frac{g}{\epsilon_m^2}(1 - e^{-\epsilon_m t}). \tag{10}$$

4. DIFFERENTIAL CORRECTIONS.

We have from (4),

$$\Delta x' = -x_0'(1 - e^{-\epsilon_m t});$$

thus $\Delta x'$ is a function of x_0' and ϵ_m, and we have by Taylor's expansion

$$\begin{aligned} d\Delta x' \equiv \Delta x'\{x_0' + dx_0', \quad \epsilon_m + d\epsilon_m\} - \Delta x'\{x_0', \quad \epsilon_m\} \\ = \frac{\partial \Delta x'}{\partial x_0'} dx_0' + \frac{\partial \Delta x'}{\partial \epsilon_m} d\epsilon_m \\ + \frac{1}{2}\left\{\frac{\partial \Delta x'}{\partial x_0'} dx_0' + \frac{\partial \Delta x'}{\partial \epsilon_m} d\epsilon_m\right\}^2 + \cdots. \end{aligned}$$

Now

$$\begin{aligned} \frac{\partial \Delta x'}{\partial x_0'} &= -(1 - e^{-\epsilon_m t}), \\ \frac{\partial \Delta x'}{\partial \epsilon_m} &= -x_0' t e^{-\epsilon_m t}, \\ \frac{\partial^2 \Delta x'}{\partial x_0'^2} &= 0, \\ \frac{\partial^2 \Delta x'}{\partial x_0' \partial \epsilon_m} &= -te^{-\epsilon_m t}, \\ \frac{\partial^2 \Delta x'}{\partial \epsilon_m^2} &= x_0' t^2 e^{-\epsilon_m t}. \end{aligned}$$

Hence

$$\begin{aligned} d\Delta x' &= -(1 - e^{-\epsilon_m t})dx_0' - tx_0' e^{-\epsilon_m t} d\epsilon_m \\ &\quad - te^{-\epsilon_m t} dx_0' d\epsilon_m + \tfrac{1}{2} t^2 x_0' e^{-\epsilon_m t} (d\epsilon_m)^2 \\ &= -(1 - e^{-\epsilon_m t})dx_0' - te^{-\epsilon_m t} d\epsilon_m \{x_0'(1 - \tfrac{1}{2} t d\epsilon_m) + dx_0'\}. \end{aligned}$$

Now $\frac{1}{2}td\epsilon_m$ will practically never exceed 0.01, and will probably be much less for almost all problems over the major part of the trajectory, hence we can neglect it, and we have

$$(11)\qquad \begin{aligned} d\Delta x' &= -(1 - e^{-\epsilon_m t})dx_0' - te^{-\epsilon_m t}d\epsilon_m(x_0' + dx_0') \\ &= -(1 - e^{-\epsilon_m t})dx_0' - X_0' te^{-\epsilon_m t}d\epsilon_m, \end{aligned}$$

where dx_0' is the difference in x' between the standard and varied trajectories at the beginning of the interval, thus

$$dx_0' = X_0' - x_0', \qquad \text{and} \qquad d\epsilon_m = E_m - \epsilon_m.$$

To obtain $d\Delta x$, we have from (6)

$$\begin{aligned} \Delta x &= \frac{x_0'}{\epsilon_m}(1 - e^{-\epsilon_m t}) \\ &= -\frac{\Delta x'}{\epsilon_m}. \end{aligned}$$

Expanding again by Taylor's series considering Δx as a function of $\Delta x'$ and ϵ_m, we have

$$d\Delta x = -\frac{d\Delta x'}{\epsilon_m} + \frac{\Delta x'}{\epsilon_m^2}d\epsilon_m + \frac{d\Delta x' d\epsilon_m}{\epsilon_m^2} - \frac{\Delta x'(d\epsilon_m)^2}{\epsilon_m^3}.$$

Substituting the values of $\Delta x'$ and $d\Delta x'$ from (4) and (11) respectively, we get

$$\begin{aligned} d\Delta x = \frac{(1 - e^{-\epsilon_m t})}{\epsilon_m}dx_0' + X_0'\frac{d\epsilon_m}{\epsilon_m}\left\{te^{-\epsilon_m t} - \frac{(1 - e^{-\epsilon_m t})}{\epsilon_m}\right\} \\ - \left\{\frac{d\epsilon_m}{\epsilon_m}\right\}^2\left\{tX_0'e^{-\epsilon_m t} - x_0'\frac{(1 - e^{-\epsilon_m t})}{\epsilon_m}\right\}. \end{aligned}$$

Considering, that x_0' and X_0' are of about the same order of magnitude, it follows that the last term as compared to the second term is as $d\epsilon_m/\epsilon_m$ is to one.

Now this will be small for all problems except where the variation considered is a large change in air density. But even then it will be appreciable only for a very short time near the origin, and hence it may be neglected and we have

$$d\Delta x = \frac{(1 - e^{-\epsilon_m t})}{\epsilon_m}dx_0' + X_0'\frac{d\epsilon_m}{\epsilon_m}\left\{te^{-\epsilon_m t} - \frac{(1 - e^{-\epsilon_m t})}{\epsilon_m}\right\}.$$

Expanding the expressions in the braces into series, it reduces to [3]

$$-\epsilon_m \frac{t^2}{2}\left\{1 - \frac{\epsilon_m t}{3/2} + \frac{\epsilon_m{}^2 t^2}{4} - \frac{\epsilon_m{}^3 t^3}{15} + \cdots\right\}.$$

A fairly close approximation to this series for small ϵ_m is $e^{-\epsilon_m t}$. Hence

$$(12) \qquad d\Delta x = \frac{(1 - e^{-\epsilon_m t})}{\epsilon_m} dx_0' - X_0' \frac{t^2}{2} e^{-\epsilon_m t} d\epsilon_m.$$

For $d\Delta y'$, we have from (8)

$$\Delta y' = -y_0'(1 - e^{-\epsilon_m t}) - \frac{g}{\epsilon_m}(1 - e^{-\epsilon_m t}).$$

The differential for the first term is identical in form with the one obtained for $d\Delta x'$, and in the second term we can safely neglect second order terms. Hence,[4]

$$(13) \quad d\Delta y' = -(1 - e^{-\epsilon_m t}) dy_0' - Y_0' t e^{-\epsilon_m t} d\epsilon_m + g\frac{t^2}{2} d\epsilon_m.$$

To obtain $d\Delta y$, we have from (10)

$$\Delta y = \frac{y_0'}{\epsilon_m}(1 - e^{-\epsilon_m t}) + \frac{g}{\epsilon_m{}^2}(1 - e^{-\epsilon_m t}) - \frac{gt}{\epsilon_m}$$

$$= -\frac{\Delta y'}{\epsilon_m} - \frac{gt}{\epsilon_m}.$$

Then considering Δy as a function of $\Delta y'$ and ϵ_m, we have

$$d\Delta y = -\frac{d\Delta y'}{\epsilon_m} + \frac{\Delta y' d\epsilon_m}{\epsilon_m{}^2} + \frac{d\Delta y' d\epsilon_m}{\epsilon_m{}^2} - \frac{\Delta y'(d\epsilon_m)^2}{\epsilon_m{}^3}$$

$$+ \frac{d\epsilon_m}{\epsilon_m{}^2} gt - gt\frac{(d\epsilon_m)^2}{\epsilon_m{}^3}.$$

After substituting for $\Delta y'$ and $d\Delta y'$, from (8) and (13) respectively, then using the same approximations as for $d\Delta x$, and retaining only first order terms for the expressions involving g only, we get

$$(14) \quad d\Delta y = \frac{(1 - e^{-\epsilon_m t})}{\epsilon_m} dy_0' - Y_0' \frac{t^2}{2} e^{-\epsilon_m t} d\epsilon_m - \frac{gt^3}{6} d\epsilon_m.$$

[3] See Appendix (*a*).

[4] See Appendix (*b*).

Collecting all formulæ, we have:

$$(11)\quad d\Delta x' = -(1 - e^{-\epsilon_m t})dx_0' - X_0' t e^{-\epsilon_m t} d\epsilon_m,$$

$$(12)\quad d\Delta x = \frac{(1 - e^{-\epsilon_m t})}{\epsilon_m} dx_0' - X_0' t e^{-\epsilon_m t} d\epsilon_m \frac{t}{2},$$

$$(13)\quad d\Delta y' = -(1 - e^{-\epsilon_m t})dy_0' - Y_0' t e^{-\epsilon_m t} d\epsilon_m + \frac{gt^2}{2} d\epsilon_m,$$

$$(14)\quad d\Delta y = \frac{(1 - e^{-\epsilon_m t})dy_0'}{\epsilon_m} - Y_0' t e^{-\epsilon_m t} d\epsilon_m \frac{t}{2} - \frac{gt^2}{2} d\epsilon_m \frac{t}{3}.$$

The last terms in (13) and (14) will prove to be negligible for most problems.

It should also be noted that the factors for (11) and (13) are the same, and that (12) and (14) differ from (11) and (13) respectively, only by an additional factor in each term, so the computations are greatly simplified.

5. THE VALUES OF E_m AND dE_m.

The best constant value to be used for ϵ_m is the mean value of ϵ over the interval, i.e.,

$$\epsilon_m = \frac{\epsilon_0 + \epsilon_t}{2}.$$

With this value of ϵ_m, the assumption that the difference between the two trajectories obtained from the integrated expressions represents the true difference, is well justified. *To obtain* $d\epsilon_m$, we have in general

$$\epsilon = \frac{G(V)H(y)}{C} = KG(V)H(y)i \qquad \left(K \equiv \frac{d^2}{W}\right)$$

or

$$lg\epsilon = lgK + lgG + lgH + lgi$$

and

$$dlg\epsilon = dlgG + dlgH + dlgi.$$

The values of $dlg_\epsilon G/VdV$ are given in table III of War Dept. Document No. 984. Let this quantity be denoted by $dlgG_T$. Now,

$$VdV = \tfrac{1}{2}d(V^2)$$

and

$$lg_e 10 = 2.3026.$$

Hence

$$dlg_{10}G = \frac{dlgG_T d(V^2)}{2 \times 2.3026}$$

$$= 0.2172\, d(V^2) dlgG_T.$$

Also,

$$dlg_{10}H = -\ .0^4 45\, dy.$$

Hence

$$dlg\epsilon = 0.2172\, d(V^2) dlgG_T - .0^4 45 dy + dlgi.$$

and the resistance function for the varied trajectory at any time is given by

$$(15) \quad lgE = lg\epsilon + 0.2172\, d(V^2) dlgG_T - .0^4 45\, dy + dlgi.$$

6. PROCEDURE.

The work is greatly expedited if the items that depend only on the elements of the standard trajectory, will be entered on the computing forms before the computing is begun.

The time intervals to be used shall as a rule be the same as those used for computing the standard trajectory.

Starting at the origin, the resistance function for the varied trajectory E_0, is computed directly from the tables, and E_t estimated, thus obtaining $d\epsilon_m$, and with the given values of dx_0' and dy_0', all the computations for the first interval can be carried out. E_t is then computed from (15) and compared with the estimated value. Using the data obtained for the end of the first interval, and again estimating E_t for the end of the second interval, all the elements can be computed for the second interval and the same process repeated for the entire trajectory.

After the first few intervals, E_t can be estimated very accurately by noticing the differences of $d\epsilon_m$. To get the correct estimate for the first interval, will require a little experience. However, it will be found, that except for the case where the variation considered is a large change in the air density, an error in the estimate of E_t will have very little effect on the computations so that it will not be necessary to repeat them.

APPENDIX.

(*a*) We have in general

$$e^x = 1 + x + \frac{x^2}{2!} + \frac{x^3}{3!} + \frac{x^4}{4!} + \cdots,$$

so that

$$e^{-\epsilon_m t} = 1 - \epsilon_m t + \frac{\epsilon_m{}^2 t^2}{2!} - \frac{\epsilon_m{}^3 t^3}{3!} + \frac{\epsilon_m{}^4 t^4}{4!} - \cdots$$

and

$$te^{-\epsilon_m t} = t - \epsilon_m t^2 + \frac{\epsilon_m{}^2 t^3}{2!} - \frac{\epsilon_m{}^3 t^4}{3!} + \frac{\epsilon_m{}^4 t^5}{4!} + \cdots.$$

Now

$$1 - e^{-\epsilon_m t} = \epsilon_m t - \frac{\epsilon_m{}^2 t^2}{2!} + \frac{\epsilon_m{}^3 t^3}{3!} - \frac{\epsilon_m{}^4 t^4}{4!} + \cdots$$

and

$$\frac{1 - e^{-\epsilon_m t}}{\epsilon_m} = t - \frac{\epsilon_m t^2}{2!} + \frac{\epsilon_m{}^2 t^3}{3!} - \frac{\epsilon_m{}^3 t^4}{4!} + \frac{\epsilon_m{}^4 t^5}{5!} - \cdots.$$

Hence

$$\begin{aligned} te^{-\epsilon_m t} - \frac{1 - e^{-\epsilon_m t}}{\epsilon_m} &= \left(t - \epsilon_m t^2 + \frac{\epsilon_m{}^2 t^3}{2} - \frac{\epsilon_m{}^3 t^4}{6} + \frac{\epsilon_m{}^4 t^5}{24} - \cdots\right) \\ &\quad - \left(t - \frac{\epsilon_m t^2}{2} + \frac{\epsilon_m{}^2 t^3}{6} - \frac{\epsilon_m{}^3 t^4}{24} + \frac{\epsilon_m{}^4 t^5}{120} - \cdots\right) \\ &= -\frac{\epsilon_m t^2}{2} + \frac{\epsilon_m{}^2 t^3}{3} - \frac{\epsilon_m{}^3 t^4}{8} + \frac{\epsilon_m{}^4 t^5}{30} - \cdots \\ &= -\frac{\epsilon_m t^2}{2}\left(1 - \frac{\epsilon_m t}{3/2} + \frac{\epsilon_m{}^2 t^2}{4} - \frac{\epsilon_m{}^3 t^3}{15} + \cdots\right). \end{aligned}$$

Now the series for $e^{-\epsilon_m t}$ is

$$1 - \epsilon_m t + \frac{\epsilon_m{}^2 t^2}{2} - \frac{\epsilon_m{}^3 t^3}{6} + \cdots.$$

As ϵ_m is a small quantity we may replace the expression

$$-\frac{\epsilon_m t^2}{2}\left(1 - \frac{\epsilon_m t}{3/2} + \frac{\epsilon_m{}^2 t^2}{4} - \frac{\epsilon_m{}^3 t^3}{15} + \cdots\right)$$

by $-\frac{\epsilon_m t^2}{2} e^{-\epsilon_m t}$, and we get,

$$\frac{d\epsilon_m}{\epsilon_m}\left\{ te^{-\epsilon_m t} - \frac{(1 - e^{-\epsilon_m t})}{\epsilon_m} \right\} = -\frac{d\epsilon_m}{\epsilon_m}\frac{\epsilon_m t^2}{2} e^{-\epsilon_m t}$$

$$= -\frac{t^2}{2} e^{-\epsilon_m t} d\epsilon_m.$$

(*b*) We have

$$\Delta y' = -y_0'(1 - e^{-\epsilon_m t}) - \frac{g}{\epsilon_m}(1 - e^{-\epsilon_m t}).$$

From (4) we have

$$\Delta x' = -x_0'(1 - e^{-\epsilon_m t}).$$

The first term in the expression for $\Delta y'$ is thus identical with the expression for $\Delta x'$ if we substitute y_0' for x_0'. Now we have shown in detail how we arrive at equation (11)

$$d\Delta x' = -(1 - e^{-\epsilon_m t}) dx_0' - X_0' t e^{-\epsilon_m t} d\epsilon_m.$$

Hence we say at once that

$$d\Delta y' = -(1 - e^{-\epsilon_m t}) dy_0' - Y_0' t e^{-\epsilon_m t} d\epsilon_m - g d\left(\frac{1 - e^{-\epsilon_m t}}{\epsilon_m} \right).$$

Now from Appendix (*a*) we have

$$\frac{1 - e^{-\epsilon_m t}}{\epsilon_m} = t - \frac{\epsilon_m t^2}{2} + \frac{\epsilon_m^2 t^3}{6} - \frac{\epsilon_m^3 t^4}{24} \cdots;$$

hence

$$d\left(\frac{1 - e^{-\epsilon_m t}}{\epsilon_m} \right) = -\frac{t^2}{2} d\epsilon_m + \frac{t^3}{3} \epsilon_m d\epsilon_m - \cdots$$

and

$$-g d\left(\frac{1 - e^{-\epsilon_m t}}{\epsilon_m} \right) = g\frac{t^2}{2} d\epsilon_m - g\frac{t^3}{3} \epsilon_m d\epsilon_m + \cdots.$$

As g is a constant equal to 9.81, and ϵ_m is a small quantity we can neglect all terms except the first. Hence we have

$$d\Delta y' = -(1 - e^{-\epsilon_m t}) dy_0' - Y_0' t e^{-\epsilon_m t} d\epsilon_m + g\frac{t^2}{2} d\epsilon_m.$$

ON FORCED PSEUDO-HARMONIC VIBRATIONS.

BY

I. K. SILVERMAN, S.M.

In a recent paper appearing in this publication * J. P. Den Hartog modified Martienssen's original solution for amplitudes of forced pseudo-harmonic vibrating systems by requiring that two conditions of equilibrium be satisfied simultaneously, viz. at the end of the stroke ($wt = 90$) and at an intermediate point $wt = 60$. In the following the writer makes use of Hamilton's Principle to obtain the motion of forced pseudo-harmonic vibrations in the form of a Fourier series. It will be seen that the method adopted contains the so-called exact solution of Den Hartog for spring characteristics made up of three sections of straight lines.

According to Hamilton's Principle the motion of any dynamical system can be expressed by:

$$\delta \int_{t_1}^{t_2} (K - V)dt = 0,$$

where K and V are the kinetic and potential energies of the system. The variation of this integral is a problem in the calculus of variations and the condition for the stationary behaviour of the integral is a differential equation known as Euler's Equation. The equation so obtained is the ordinary differential equation of motion.

THE DIFFERENTIAL EQUATION FOR FORCED PSEUDO-HARMONIC VIBRATIONS BY MEANS OF THE CALCULUS OF VARIATIONS.

Let the disturbing force be given by $P \sin wt$; the spring characteristic by $kf(x)$. The force acting on the spring is then:

$$[kf(x) - P \sin wt].$$

$$V = \int_0^x (kf(x) - P \sin wt)dx,$$

$$K = \frac{1}{2}\frac{W}{g}\dot{x}^2 = \frac{1}{2}m\dot{x}^2.$$

* JOURNAL OF THE FRANKLIN INSTITUTE, October, 1933.

From Hamilton's Principle:

$$\delta I = \delta \int_{t_0}^{t_1} \left[\frac{1}{2} m\dot{x}^2 - \int_0^x (kf(x) - P \sin wt) dx \right] dt = 0$$

$$= \int_t^{t_1} [m\ddot{x} + kf(x) - P \sin wt] dx dt = 0 \qquad (1)$$

under the condition that

$$[m\dot{x}\delta x]_{t_0}^{t_1} = 0. \qquad (2)$$

Since x is arbitrary, (1) is true when

$$m\ddot{x} + kf(x) - P \sin wt = 0. \qquad (3)$$

However in the method used below our starting point is equation (1) and our limits are $t_0 = 0$ and $t_1 = \frac{T}{4}$, i.e. a quarter cycle.

Case I $\qquad kf(x) = F + kx$:

Assuming that the motion can be expressed as a Fourier series we have:

$$x = a_1 \sin wt + a_3 \sin 3wt + a_5 \sin 5wt + \cdots. \qquad (4)$$

The values of the constants $a_1\ a_3\ a_5 \ldots$ are obtained by the use of (1) and the fulfillment of the condition expressed by (1) yields as many equations as there are unknown coefficients. Thus if we use two terms in (4)

$$\delta x = \delta a_1 \sin wt + \delta a_3 \sin 3wt.$$

Inserting this expression into (1) and noting that the variations δa_1, δa_3 are independent we obtain the following two equations:

$$\int_0^{\pi/2w} [A \sin^2 wt + B \sin wt \sin 3wt + F \sin wt] dt = 0,$$

$$\int_0^{\pi/2w} [B \sin^2 3wt + A \sin wt \sin 3wt + F \sin 3wt] dt = 0,$$

where

$$A = ka_1 - ma_1w^2 - P,$$

$$B = ka_3 - 9ma_3w^2.$$

Performing the integrations we have

$$a_1 = \frac{P - \frac{4F}{\pi}}{k - mw^2}; \quad a_3 = \frac{-\frac{4F}{3\pi}}{k - 9mw^2}.$$

If the first three terms of (4) had been used the constants would be as follows:

$$a_1 = \frac{P - \frac{4F}{\pi}}{k - mw^2}; \quad a_3 = -\frac{\frac{4F}{3\pi}}{k - 9mw^2}; \quad a_5 = -\frac{\frac{4F}{5\pi}}{k - 9mw^2}.$$

Case II $\qquad kf(x) = k(x - a)$:

Substitute for F in case I, $F = -ka$.

$$a_1 = \frac{P + \frac{4ka}{\pi}}{k - mw^2}; \quad a_3 = \frac{\frac{4ka}{3\pi}}{k - 9mw^2}; \text{ etc.}$$

Case III $\qquad kf(x) = px^2$:

If two terms are taken in (4), the two simultaneous equations which determine a_1 and a_3 are

$$\frac{A\pi}{4} - \frac{4}{15}pa_1a_3 + \frac{2}{3}pa_1^2 + \frac{18}{35}pa_3^2 = 0,$$

$$-\frac{9ma_3\pi w^2}{4} + \frac{36}{35}pa_1a_3 - \frac{2}{15}pa_1^2 - \frac{2}{9}pa_3^2 = 0,$$

where

$$A = -(a_1mw^2 + P).$$

If only one term is taken

$$a_1 = \frac{3\pi}{16p}mw^2 + \sqrt{\left(\frac{3\pi}{16}\frac{mw^2}{p}\right)^2 + \frac{3\pi P}{8p}}.$$

Carotin and Vitamin A.—Carotin is a complex hydrocarbon which occurs in nature as a lipochrome or fat pigment; it is the precursor of the fat-soluble vitamin A which protects the body from the eye disease known as keratomalacia and from infections. This vitamin is formed by oxidative cleavage of a carotin molecule into two equal halves, and the conversion of each half into a complex alcohol. WOLF v. DRIGALSKI (*Zeit. Vitaminforschung*, 1934, III, 37–74) has suggested that vitamin A be designated the epithelium-protective vitamin. His researches show that 100 cc. of normal blood usually contain from a trace to 0.01 milligram of carotin, although a maximum valve of 0.27 milligram was noted. The body stores carotin and vitamin A abundantly, chiefly in the liver.

J. S. H.

The Ferox Process for Fiber Board.—This process is designed to proof fiber board against attack by dry rot and termites. It consists of making a "slurry" from alum and sodium arsenite, and pumping this directly into the head box of the board forming machines, where it mixes with the fibers, is almost completely filtered out in the board and on drying becomes an insoluble complex, difficult to leach out. The treatment does not alter the physical properties of the products so treated, nor interfere with other operations.

C.

Extinguishing Clothing Fires with Carbon Tetrachloride.—At the March Meeting, Division of Industrial and Engineering Chemistry, J. C. OLSEN, G. E. FERGUSON AND L. SCHEFLAN reported the results of their tests on extingushing with carbon tetrachloride fires from cotton, woolen and silk clothing burning in closed rooms. Contrary to popular belief phosgene was not found in any of the fires. Experiments showed that this gas is rapidly and completely decomposed by the ammonia produced when woolen or silk clothing is decomposed by heat. Chlorine, hydrochloric acid, prussic acid, ammonia, hydrogen sulphide and sulphur dioxide were found in the gases produced by the fires. It was concluded from the experiments that the gases produced by extinguishing clothing fires with carbon tetrachloride do not increase the toxicity of those gases produced by the burning clothing.

C.

THE PROBABLE EFFECT OF TIDAL POWER DEVELOPMENT ON BAY OF FUNDY TIDES.

BY

H. B. HACHEY, M.Sc.,

Atlantic Biological Station.

INTRODUCTION.

A number of problems of economic importance arise out of suggested tidal power development in the Passamaquoddy area of the Bay of Fundy. Two large bays open into the Bay of Fundy near its mouth from the northwest. These bays are partially shut off from the Bay of Fundy by a series of islands large and small which offer exceptional opportunities for the construction of dams. The tidal amplitudes in this region are in the neighbourhood of twenty feet. Suggested development calls for the construction of dams to shut off Passamaquoddy Bay and Cobscook Bay from the Bay of Fundy. Suitable gates will allow the filling of Passamaquoddy Bay at high water and the emptying of Cobscook Bay at low water. In this manner a difference in level will exist between Passamaquoddy Bay and Cobscook Bay. The power house will be situated between Passamaquoddy Bay and Cobscook Bay in order to use the head of water created to develop electrical energy.

Phenomenal tides exist in the Bay of Fundy and it is of interest as well as of practical importance to determine the effect of the proposed development on the phenomenon of the tides in the Bay of Fundy.

The utilization of tidal energy has been discussed by many writers and several methods have been suggested to transform this energy possessed by the water in motion to some more useful form. In some cases a practical method has been evolved and used.

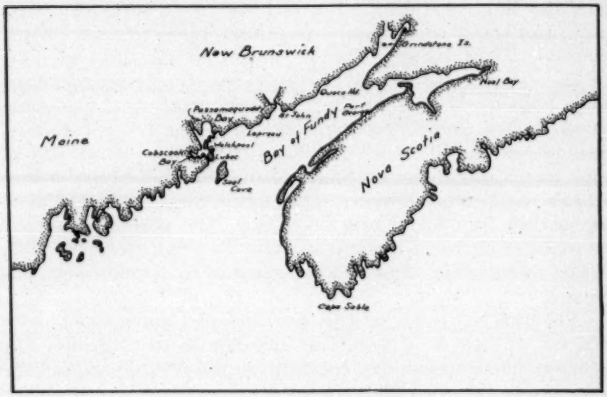
Of the various practical methods suggested, the basin system is simple in principle, and is probably of the greatest importance from an engineering point of view because it

permits of large scale installations. The basin system consists principally of one or more basins which are cut off from the sea by dams. By use of suitable gates and by making use of the tides, a head of water is maintained between one basin and another, or between one basin and the sea. Making use of the potential energy which is stored in one of the basins, turbines and auxiliary machinery transform it into electrical energy.

THE POWER POSSIBILITIES OF BAY OF FUNDY TIDES.

The tides in the Bay of Fundy are the largest in the world (Marmer, p. 217, 1926). The bay itself (Fig. 1) comprises an area of approximately 6000 square miles. The mouth of

FIG. 1.



Map of the Bay of Fundy.

the bay is approximately 85 miles in width. The average depth is about 275 feet and the depths decrease gradually from the mouth to the head. The mean range of the tide varies from about 9 feet at Cape Sable to about 44 feet at Noel Bay (Tide tables, 1933). The spring tides are about 15 per cent. greater, giving for the spring range at Noel Bay a

value of about 51 feet. The average range for the bay is about 22 feet. Using the above data the available energy amounts to about 175,000,000 horse power.

It is little wonder then that the power possibilities of the Bay of Fundy tides have attracted and engaged the attention of some of our foremost engineers. Several projects have been suggested for the purposes of power development. The largest of these projects is in effect an application of the basin system to develop some of the energy present in the waters of the Bay of Fundy. The proposal is to shut off the waters of Passamaquoddy Bay and Cobscook Bay (Fig. 2). These two bays will constitute the two basins of the system. From Passamaquoddy Bay approximately 380,000 cu. feet of water per second will be run continuously through the power house into Cobscook Bay. From 1¾ hours before H. W. until 25 minutes after H. W., water will flow into Passamaquoddy Bay through gates at Letite and Kendall Head. The "draw down" of the water in Passamaquoddy Bay between successive refills will be only 5 feet. From 3½ hours before L. W. until 15 minutes after L. W., water will flow out of Cobscook Bay. The possibilities of the scheme can be seen from a consideration of the energy that is potentially present in the tidal waters that enter Passamaquoddy Bay. The area of Passamaquoddy Bay is approximately 100 sq. miles. Taking the mean range of the tide as 20 feet, the available energy amounts to 2,500,000 horse power. It is stated that between 500,000 and 700,000 horse power can be developed profitably at a cost of about $100,000,000.

THE PROBLEM.

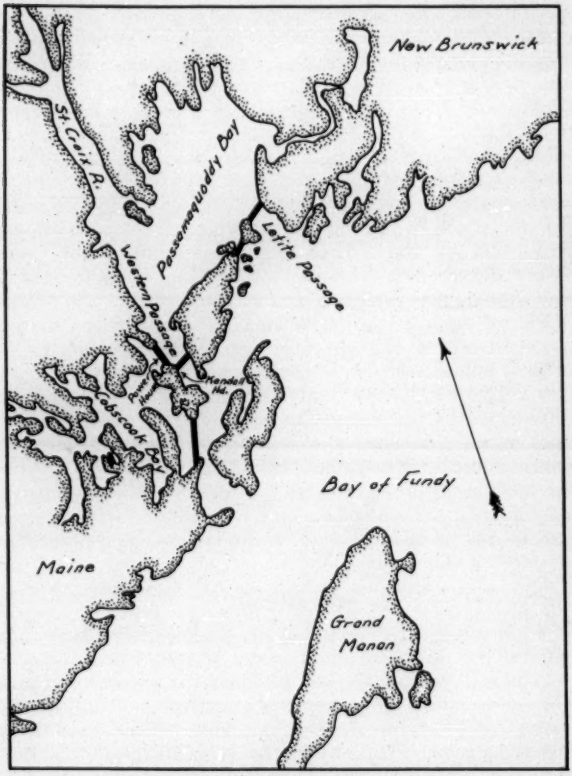
From the meager outline of the scheme given above it is noted that to utilize the tidal energy, Passamaquoddy Bay is to be closed off from the Bay of Fundy by a series of dams. There are a number of problems of great economic importance arising out of a proposition of this kind. This paper deals with the possible effects of this scheme on the tides of the Bay of Fundy.

TIDES IN THE BAY OF FUNDY.

The tidal range in the Bay of Fundy increases from a value of 9 feet at the mouth to 44 feet at Noel Bay. Many

bays along the Atlantic sea-board although possessing physical features similar to those of the Bay of Fundy have tidal ranges

FIG. 2.



Passamaquoddy Bay, showing proposed tidal power development.

of only 4 or 5 feet. From this it is evident that although the gradual decreasing depth as well as the gradual narrowing of

the bay are probably responsible in part for the increase in tidal range from the mouth of the bay to the head (due to the cooping up of the waters), yet we must look for some further explanation of the extremely large tides in the Bay of Fundy.

There is very little retardation in the time of the tide as it proceeds up the bay (Tide tables, 1933). This fact, together with the increasing range, proves conclusively that the tidal phenomenon in this region is of the "stationary wave" type (Marmer, p. 221, 1926). Several writers have likened the phenomenon to that of a body of water oscillating in a rectangular trough, the natural period of which is given by the formula,

$$T = \frac{4L}{\sqrt{gh}},$$

where L is the length of the trough,

h is the depth of the water, and

g is the acceleration due to gravity.

Using this formula various values between 11 and 13 hours have been obtained for the natural period of oscillation of the waters of the Bay of Fundy.

The nature of an oscillation in a rectangular trough is illustrated in Fig. 3. At the point P, the amplitude of oscilla-

FIG. 3.

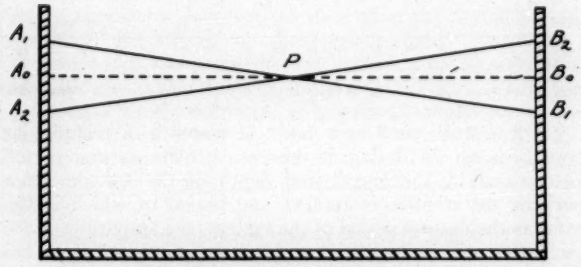
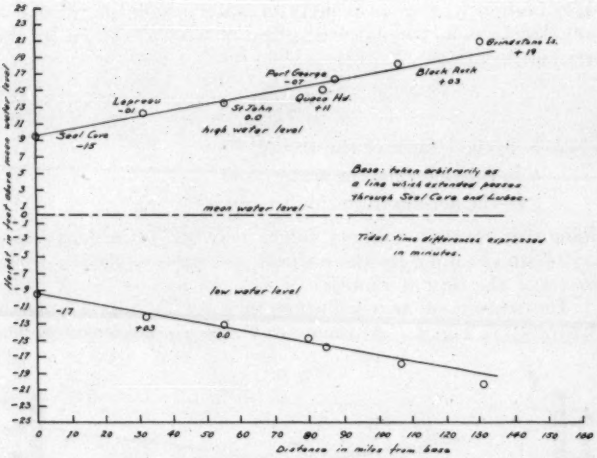


Diagram illustrating oscillations in a trough.

tion is zero. The Bay of Fundy could be likened to one-half of the rectangular trough. In Fig. 4, the tidal ranges for

various points within the bay have been plotted. The tidal time differences are small. By producing the graph to the left, a point is found where the range of the tide is theoretically zero. This point has been located in this manner at the edge of the continental shelf. Comparing Figs. 3 and 4, the similarities between the oscillations in a rectangular trough and the tidal oscillations in the Bay of Fundy are evident.

FIG. 4.



High and low water levels in the Bay of Fundy in relation to the distance from an arbitrary base.

If a system, such as a body of water in a rectangular trough, is set oscillating, it does so with its natural period determined by the length and depth of the trough. If a periodic disturbance is applied, the period of which is the same as the natural period of the system, the amplitude of the oscillation will be increased and will be prevented from becoming infinite by the various forces of resistance. In the Bay of Fundy, the disturbing force is the resultant tide producing forces. The natural period of oscillation of the bay is apparently the same as the periodic disturbing force. The

amplitude of the oscillation is controlled by the various forces of resistance.

It can be shown also, that even though a progressive wave must accompany the phenomenon of the tides in this region, the effects are minimized by the presence of the stationary wave. The velocity of a progressive wave (when the wave-length is large in comparison with the depth) is given by the formula,

$$v = \sqrt{gh},$$

where v is the velocity,

h is the depth, and

g is the acceleration due to gravity.

The depth of the water in the Bay of Fundy is only a small fraction of the length of a tidal wave (Warburg, 1922). Taking the average depth as 280 feet, we obtain $v = 94.6$ feet per second. Using this value, the time required for the progressive wave to travel from Grand Manan to Grindstone Island, a distance of 130 miles, is given as 2 hours. The tide tables show that the tidal time difference is only 22 minutes.

THE PROBABLE EFFECT OF CLOSING OFF PASSAMAQUODDY BAY.

The extremely large tides of the Bay of Fundy are seemingly determined primarily by the natural period of oscillation of the waters of the bay. Length and depth are factors which determine the natural period of oscillation of a bay. Other factors may enter however, to determine the actual period with which the waters contained will oscillate. The following simple experiments with models have demonstrated this fact.

Troughs were constructed (Fig. 5) to approximate to the actual model of the Bay of Fundy and Passamaquoddy Bay. The troughs were filled with water to a suitable depth and an oscillation was set up. The general results may be noted as follows:

1. Natural periods of oscillation of A and B equal
   - (a) Closing off A resulted in an increased amplitude in B.
   - (b) Closing off A did not affect the period of oscillation of the waters in B.

2. Natural periods of oscillation of *A* and *B* different.
   (*a*) Closing off *A* resulted in a decrease in the period of oscillation of the waters in *B*.

The results obtained in 1 (*b*) and 2 (*a*) can be deduced theoretically by a consideration of the compounding of two vibrations. The results obtained in 1 (*a*) can be deduced theoretically by energy considerations.

Considering Passamaquoddy Bay as a unit by itself it is quite probable that left to itself various forms of seiches may be set up. As part of the Bay of Fundy system an oscillation may be communicated to it if conditions are suitable. Fol-

FIG. 5.

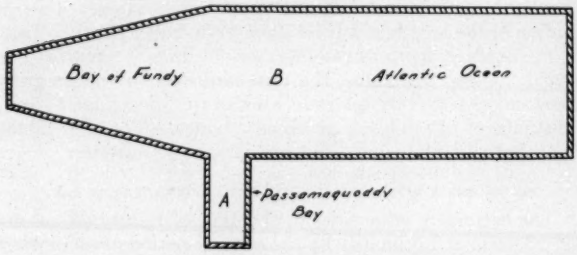


Diagram of experimental model (not drawn to scale).

lowing the experiments with models, self recording tide gauges were set up at various points in Passamaquoddy Bay. The records were analysed and gave little indication of oscillatory movement of the waters. This was to be expected according to the results of Japanese investigators. Honda and others (1907) made extensive investigations of the conditions necessary for the communicating of oscillations from a large body of water to bays and estuaries. As a result they have reached the following conclusions:

1. In a bay of considerable area or a shallow bay communicating by a narrow opening the secondary undulation is in ordinary cases inconspicuous.

2. In a deep bay or estuary, the breadth of which is not large in comparison with its length, the secondary undulations are most pronounced.

The explanation then for the absence of a pronounced oscillation in Passamaquoddy Bay rests in the fact that conditions at the mouth of the bay are unsuited for the transmission of the oscillation from the Bay of Fundy. Coupled with this explanation must be the supposition that the natural period of Passamaquoddy Bay, as determined by the length, is unsuited for resonance with the movement of the tidal waters. The probable effect of closing off Passamaquoddy Bay is to be determined then by a consideration of the energy changes that will result.

ENERGY CONSIDERATIONS.

The general result obtained for the amount of energy stored in Passamaquoddy Bay (35×10^{12} ft. lbs.) during six hours points to the fact that the waters entering the Bay of Fundy sacrifice this energy to the Passamaquoddy Bay region. The amount of energy dissipated at the entrances to Passamaquoddy Bay must also be large as the tide rips and whirlpools produced are strong and dangerous. Hence it is easily seen that if this energy was conserved by the waters of the Bay of Fundy and carried forward, the range of the tides in the Fundy region would be increased. A simple calculation determines the result. A tide curve in the Bay of Fundy region is of the nature of a sine curve. Consequently the tidal amplitude varies directly as the square root of the energy.

Calculated energy carried into the Bay of Fundy in six hours..	25×10^{14} ft. lbs.
Calculated energy transferred to Passamaquoddy Bay in six hours	35×10^{12} ft. lbs.
Percentage increase in the energy of the waters of the Bay of Fundy if Passamaquoddy Bay were shut off	1.4 per cent.
Resulting increase in tidal amplitude	1.2 per cent.

If we give an approximate value to the energy that is now lost in forcing the waters through the entrances to Passamaquoddy Bay the percentage increase in the tidal amplitudes in the Bay of Fundy would be greater. Suppose that this energy lost amounts to about 35×10^{12} ft. lbs. The resulting percentage increase in energy in the Bay of Fundy following the closing off of Passamaquoddy Bay would be 2.8 per cent. The resulting percentage increase in the

amplitude of the Fundy tides would then be 1.7 per cent. The effects at several points are noted as follows:

Welchpool:
At spring tides an increase in range of 0.4 ft. St. John:
At spring tides an increase in range of 0.45 ft.
Grindstone Is.
At spring tides an increase in range of 0.7 ft.
Burntcoat Hd.
At spring tides an increase in range of 0.85 ft.

SUMMARY.

1. The power possibilities for the Bay of Fundy and Passamaquoddy Bay are indicated by the available energy as follows:

(*a*) Bay of Fundy.....175,000,000 horse power.
(*b*) Passamaquoddy Bay..... 2,500,000 horse power.

2. The tidal phenomenon of the Bay of Fundy is of the stationary wave type. The combined action of this stationary wave and a progressive wave coupled with the physical features of the bay are responsible for the phenomenally large tides in the Bay of Fundy.

3. The stationary wave oscillations of the Bay of Fundy are not transmitted to Passamaquoddy Bay.

4. Closing off Passamaquoddy Bay will not effect the natural period of oscillation of the waters of the Bay of Fundy.

5. Closing off Passamaquoddy Bay will result in additional energy being reserved to the Bay of Fundy and bring about increased tidal amplitudes.

REFERENCES.

HONDA, TERADA, YOSHIDA, AND ISITANI, Secondary Oscillations of Oceanic Tides. *Jour. Coll. of Science*, Japan, 1907.
MARMER, H. A. The Tide. 282 pp. Appleton, New York. 1926.
Tide Tables for St. John, N. B. 30 pp. Dept. of Marine, Ottawa. 1933.
WARBURG, H. D. Tides and Tidal Streams, pp. 95, C. U. P., London, 1922.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

MEASURING THE AIR PERMEABILITY OF PAPER AND OTHER SHEET MATERIALS.

A sensitive instrument has been developed at the Bureau for measuring the rate at which air passes through paper and porous materials in sheet form. The air permeability of paper is significant in a great many ways. Sheathing paper used in the walls of houses should be air-right to minimize heat losses from air infiltration. Many food products require air-tight wrappers; others require greaseproof wrappers, and there is a close relation between the permeability of air and the permeability of oils. A well closed structure, not too permeable to air, is desired in cigarette paper to insure good draft through the burning tobacco. The dielectric strength of paper used in insulating electric cables is closely related to the air permeability. Certain types of bag paper require a fairly definite air permeability, since the process of filling the bags demands that the paper act as a filter to retain powdered material as the air escapes through the paper. The air permeability test is sometimes used to predict the rate of absorption of the saturant in the preparation of such materials as roofing felt, paraffined paper, sheathing paper, bakelite, and cable paper, since both properties depend upon the porosity of the untreated sheet. For the same reason air permeability is related to the rate of drying of printing ink on printing papers.

A preliminary survey indicated that the most common sources of error in existing instruments for testing the air permeability of paper are leakage, especially at the edges of the specimen, fluctuations in driving pressure, lack of sensitivity, and restricted range. The new instrument, which is described in RP681 in the May number of the *Journal of Research*, contains a permeability cell of novel design, in which an annular cell surrounds the inner testing cell. The air flow is so regulated that there is no lateral pressure gradient at the

* Communicated by the Director.

boundary of the inner cell, and hence no leakage into or out of it. The pressure regulator is a form of automatic diaphragm valve designed to maintain a very steady pressure drop across the instrument. The amount of air, which in a given time reaches the inner cell by flowing through the specimen under the influence of this constant pressure difference, is measured with a capillary flow meter containing four carefully calibrated capillary tubes. Results are reproducible on an identical area to within a few tenths of one per cent. The range of the instrument is about a thousand times that of most other instruments available for the purpose. It will accommodate materials of any thickness up to half an inch, and it is not necessary to cut them in order to make the test. Tests can be made rapidly, since the element of time is taken care of in the calibration and the duration of the test need not be measured. The test area is larger than is usually found in air permeability instruments in order better to sample the material. The instrument is well adapted to the testing of leather and some other sheet materials.

PSYCHROMETRIC CHARTS.

The psychrometric charts, issued late in 1933 as Bureau of Standards Miscellaneous Publication no. 143, were out of print early in March. A second printing was completed during May and the charts are now available again at a price of five cents per copy.

These charts are designed for use at atmospheric pressures close to the standard for sea level, the ranges being 70 to 80 cm. Hg and 28 to 31.5 in. Hg. A new series of charts is being prepared in both Fahrenheit and Centigrade units, each chart being accurate over a range of pressures from 10 cm. Hg (or 5 in. Hg) to 10 atmospheres.

As two operations are required to determine the humidity when using these new charts, they will supplement, rather than replace, the old ones. It is expected that the new charts will be available about July 1. Price will be announced later. Orders for either or both of these charts should be sent to the Superintendent of Documents, Government Printing Office, Washington, D. C.

COLD ROLLING OF SINGLE CRYSTALS OF COPPER.

As part of a study of the effect of mechanical rolling on the hardness of copper, a number of 5/8 inch round rods of oxygen-free copper were prepared in the form of single crystals. The crystalline orientation with respect to the axis of the rod was determined by etching a polished, hemispherical end of the rod. Two specimens were cold rolled; in one case the single crystal was cold rolled parallel to a cube face, in the other at an angle to the cube face and cube edges. The behavior during rolling and the hardness determinations made on the cold rolled coupons indicated that these properties are not materially affected by the orientation of the copper crystals nor by the change from ordinary, polycrystalline material to large single crystals of copper.

WEAR OF METALS.

In the course of a study of the effect of surface oxide films on the metal-to-metal wear of steels, it has been found that hardened-and-tempered plain carbon steels, tested in a hydrogen atmosphere on the Amsler wear machine, show rather abrupt transitions from one condition of wear which is characteristic of low tempering temperatures to a distinctly different condition of wear characteristic of higher tempering temperatures.

The wearing of specimens tempered at the lower temperatures is accompanied by the formation of surface films and the rate of wearing is relatively low; on the other hand, the wearing of specimens tempered at the higher temperatures results in a very bright, rough surface and the rate of wear is relatively *very* high. Tests recently completed have shown that the tempering temperature which corresponds with this change in type of wear increases with increasing carbon content of the steel. It is close to 200 C in a 0.4 per cent. C steel, about 300 C in a 0.8 per cent. C steel and between 400 and 500 C in a 1.3 per cent. C steel.

The preliminary study of this behavior has been made, for the most part, under a given set of conditions as regards the contact pressures between the specimens and the amount of "slip" between the two specimens rotating at slightly different speeds.

SUPPLEMENTARY 10,000-kc/s STANDARD FREQUENCY TRANSMISSIONS.

A series of supplementary experimental radio transmissions on 10,000 kilocycles per second from the Bureau's standard frequency station WWV, Beltsville, Md., was started on Thursday, May 3, and will be continued each Thursday during May from noon to 2 P.M., Eastern Standard Time. These transmissions are additional to the regular 5000-kc/s transmissions and are being conducted in a similar manner.

As the object is to provide a standard-frequency service to the western half of the United States, reports are particularly desired from points more than 500 miles from Washington on how well the 10,000 kc. frequency is received and as to its utility in checking frequency. The data desired are approximate field intensity, fading characteristics, and the suitability of the transmissions for frequency measurements. It is suggested that in reporting on intensities, the following designations be used where field intensity measurement apparatus is not used: (1) hardly perceptible, unreadable; (2) weak, readable now and then; (3) fairly good, readable with difficulty; (4) good, readable; (5) very good, perfectly readable. A statement as to whether fading is present or not should be included and if fading occurs, its characteristics should be described, such as time between peaks of signal intensity. The type of receiving set and type of antenna used should be stated. The Bureau would also appreciate reports on the use of the transmissions for purposes of frequency measurement or control.

All reports and letters regarding the transmissions should be addressed Bureau of Standards, Washington, D. C.

THE FRANKLIN INSTITUTE.

STATED MONTHLY MEETING, MAY 16, 1934.

The stated monthly meeting of the Institute was called to order at three-thirty P.M. by the President of the Institute, Mr. Nathan Hayward.

The President stated that the minutes of the April meeting had been printed in full in the May number of the JOURNAL of the Institute, and that, if there were no objections, the minutes would stand approved as printed. No objection was offered and the minutes were declared approved.

The next item of business was the presentation of medals which had been recommended by the Committee on Science and the Arts and the award of Certificates of Honorary Membership.

The order of the awards proceeded as follows:

	Sponsors
Presentation of Certificates of Merit to	
ALBERT ALLEN Winchester, Massachusetts	Mr. William G. Ellis
JOSEPH GRUNDY SHRYOCK, M.C.E. Philadelphia, Pennsylvania	Mr. Henry H. Quimby
Presentation of Longstreth Medal to	
WILLIAM EDWIN SYKES Buffalo, New York	Mr. Coleman Sellers, 3rd.
Presentation of Wetherill Medals to	
JOHANN B. OSTERMEIER Augsburg, Germany	Mr. W. H. Fulweiler
Received by the Consul for Germany at Philadelphia	
E. NEWTON HARVEY, PhD. Princeton University Princeton, New Jersey and ALFRED LEE LOOMIS, LL.B. Tuxedo Park, New York	Dr. George S. Crampton
Presentation of Levy Medal to	
KENNETH T. BAINBRIDGE, Ph.D. Cambridge, England	Dr. W. R. Wright
Received by Dr. W. F. G. Swann	
Presentation of Potts Medal to	
ERNST GEORG FISCHER Washington, D. C.	Dr. T. D. Cope
Presentation of Cresson Medals to	
STUART BALLENTINE Boonton, New Jersey	Mr. W. C. Wagner

UNION SWITCH AND SIGNAL COMPANY — Mr. James D. Lee, Jr.
Swissvale, Pennsylvania

Received by Mr. W. H. Cadwallader, Vice-President

Presentation of the Franklin Medal and Certificate of Honorary Membership to
HENRY NORRIS RUSSELL, A.M., Sc.D., Ph.D. — Dr. H. J. Creighton
Princeton University
Princeton, New Jersey

Presentation of the Franklin Medal and Certificate of Honorary Membership to
IRVING LANGMUIR, A.M., ScD., D.Ing., LL.D. Ph.D. — Dr. H. J. Creighton
General Electric Company
Schenectady, New York

PAPERS

"The Atmospheres of the Stars," Dr. Henry Norris Russell.
"The Mechanical Properties of Monomolecular Oil Films," Dr. Irving Langmuir.

The President then declared the meeting adjourned, at five-ten P.M.

HOWARD MCCLENAHAN,
Secretary

(An extended account of the proceedings of Medal Day will be published in an early issue of the JOURNAL.)

COMMITTEE ON SCIENCE AND THE ARTS.

(*Abstract of Proceedings of Stated Meeting held Wednesday, May 9, 1934.*)

HALL OF THE COMMITTEE,
PHILADELPHIA, MAY 9, 1934.

MR. CHARLES D. GALLOWAY *in the Chair.*

The following reports were presented for first reading:

No. 2982: Method of, and Apparatus for, Dust Removal.
No. 2983: Tri-Dimensional Vibrograph.
No. 2986: Optical Lever and Optical Strain Gage.

GEO. A. HOADLEY,
Secretary to the Committee.

MEMBERSHIP NOTES.

ELECTIONS TO MEMBERSHIP.

(Stated Meeting, Board of Managers, May 23, 1934.)

RESIDENT.

MR. LEON EDELSON, Patent Attorney, Philadelphia, Pa.
MR. GEORGE L. HARRISON, Philadelphia, Pa.
MISS ANNA H. HAYWARD, Teacher, The Shipley School, Bryn Mawr, Pa. For mailing: Wayne, Pa.
MR. JOSEPH G. SHRYOCK, Bridge and Structural Engineer, Belmont Iron Works, Philadelphia, Pa.
MR. THOMAS J. TOWN, Guard, The Franklin Institute. For mailing: 5040 City Line, Philadelphia, Pa.
MR. D. IRVING TRAINER, Chemical Executive, General Chemical Company, Philadelphia, Pa. For mailing: Media, Pa.
MR. WHITNEY WEINRICH, Research Chemical Engineer, Gulf Refining Company, Philadelphia, Pa. For mailing: Stratford Court, Lansdowne, Pa.
MR. F. P. WITMER, Director, Department of Civil Engineering, University of Pennsylvania, Philadelphia, Pa. For mailing: Radcliff Road and Lodge's Lane, Cynwyd, Pa.

NON-RESIDENT LIFE.

MR. JOHN B. RUMBOUGH, Asheville, North Carolina.

STUDENT.

MISS ANNE HOLLOWAY, Philadelphia, Pa.
MR. LOUIS MOYD, Philadelphia, Pa.
MR. HERBERT M. STAUFFER, Philadelphia, Pa.

MUSEUM MEMBERSHIP, FAMILY.

MR. SUMMERFIELD HAGERTY, 507 East Gravers Lane, Chestnut Hill, Pa.
MR. LOUIS W. VAN METER, 1632 Chestnut Street, Philadelphia, Pa.
MR. J. B. WARRINER, Drake Hotel, 1512 Spruce Street, Philadelphia, Pa.

INDIVIDUAL.

MRS. RICHARD L. BINDER, Philadelphia, Pa.
MRS. PHILIP S. COLLINS, Wyncote, Pa.
MR. EUGENE F. FISHER, 926 North Forty-eighth Street, Philadelphia, Pa.
MR. ALEXANDER COXE GROOME, Pennbrook Apartments, Overbrook, Pa.
MR. CHARLES F. KELLEY, JR., 127 Pelham Road, Germantown, Philadelphia, Pa.
MISS JANE GRAHAM MASON, School House Lane, Germantown, Philadelphia, Pa.
MR. J. R. MECOUCH, 15 North Thirty-second Street, Philadelphia, Pa.
MRS. ARTHUR V. MORTON, 1015 Clinton Street, Philadelphia, Pa.
MR. HERMAN N. SILVER, 1319 Banker Trust Building, Philadelphia, Pa.

MR. STANLEY C. SNOW, 1401 Arch Street, Philadelphia, Pa.
MRS. THOMAS J. TOWN, 5040 City Line, Philadelphia, Pa.

CHANGES OF ADDRESS.

MR. G. H. CONDICT, 922 Central Avenue, Plainfield, N. J.
MR. ARMIN ELMENDORF, Research Trust Ltd., 54 Victoria Street, London, S. W. 1, England.
MR. ROBERT GRIMSHAW, 4 Cottage Place, Leonia, N. J.
MR. E. S. HIGGINS, 353 Lodges Lane, Bala-Cynwyd, Pa.
DR. RALPH MODJESKI, Architects Building, Seventeenth and Sansom Streets, Philadelphia, Pa.
MR. WALTER PALMER, P.O. Box No. 406, Chester, Pa.
MR. JOSEPH ROSSMAN, 1266 New Hampshire Avenue, Washington, D. C.
MR. PEDRO G. SALOM, The Lenox, Thirteenth and Spruce Streets, Philaelphia, Pa.
MR. RICHARD W. TORBET, 431 East Montana Street, Philadelphia, Pa.
DR. J. STEPHEN VAN DER LINGEN, The Fuel Research Institute of South Africa. P.O. Box 217, Pretoria, South Africa.
MR. H. H. VAUGHAN, 1111 Beaver Hall Hill, Montreal, P. Q. Canada.

NECROLOGY.

Dr. Louis W. Austin, Washington, D. C.
Mr. James Hartness, Springfield, Vt.
Mr. Arthur F. Poole, Ithaca, New York.
Mr. Walter Wood, Philadelphia, Pa.
Mr. George M. Yorke, New York City.

LIBRARY NOTES.

RECENT ADDITIONS.

ABBOTT, ARTHUR L. National Electrical Code Handbook. Based on the 1933 Edition of the National Electrical Code. Second edition. 1934.
ADAMS, HADDON C. The Elements of Reinforced Concrete Design. 1933.
American Foundrymen's Association. Transactions 1932–1933. Volumes 40 and 41. 1933–1934.
American Public Health Association and Association of Official Agricultural Chemists. Standard Methods of Milk Analysis, Bacteriological and Chemical. Sixth edition. 1934.
American Society for Testing Materials and The American Foundrymen's Association. Symposium on Cast Iron Held at a Joint Meeting of The

American Foundrymen's Association and The American Society for Testing Materials, Chicago, Ill., June 26, 1933.

BARNARD, WILLIAM N., FRANK O. ELLENWOOD, AND CLARENCE F. HIRSHFELD. Elements of Heat-Power Engineering. Part III: Auxiliary Equipment, Plant Ensemble, Air Conditioning, and Refrigeration. Third edition of part of Hirshfeld and Barnard's Elements of Heat Engineering, completely revised. 1933.

BERINGER, H. R. Simple Determinative Mineralogy. 1931.

BERL, ERNST. Berl-Lunge Chemisch-technische Untersuchungsmethoden. Bd. 2–5. Achte, vollständig umgearbeitete und vermehrte Auflage. 1934.

BONZEL, MAURICE. Le Tréfilage de l'Acier. 1934.

BRIDGMAN, P. W. Thermodynamics of Electrical Phenomena in Metals. 1934.

CAMERON, JAMES R., AND OTHERS. Motion Picture Projection and Sound Pictures. Fifth edition (Fifteenth Year). 1933.

Chemical Society. Annual Reports on the Progress of Chemistry for 1933. Volume 30. 1934.

CHILDS, W. H. J. Physical Constants Selected for Students. 1934.

DAYNES, H. A. Gas Analysis by Measurement of Thermal Conductivity. 1933.

DÉGOUTIN, N. Étude Pratique des Minerais. Guide pour les Missions d'Études Minières et les Essais Industriels de Traitement. 1934.

ENGELHARDT, VICTOR. Handbuch der technischen Elektrochemie. Dritter Band: Die technische Elektrolyse im Schmelzfluss. 1934.

EUCKEN, A., AND K. L. WOLF. Hand- und Jahrbuch der chemischen Physik. Band 6, Abschnitt 2–3. 1933.

FRENKEL, J. Wave Mechanics: Advanced General Theory. 1934.

GREGG, J. L. The Alloys of Iron and Tungsten. First edition. Alloys of Iron Research Monograph Series. 1934.

GREINER, EARL S., J. S. MARSH AND BRADLEY STOUGHTON. The Alloys of Iron and Silicon. First edition. Alloys of Iron Research Monograph Series. 1933.

GRIMSEHL, E. A Textbook of Physics. Edited by R. Tomaschek. Authorized Translation from the Seventh German Edition by Winifred M. Deans. Volume IV: Optics. 1933.

HASSEL, O. Kristallchemie. Wissenschaftliche Forschungsberichte-Naturwissenschaftliche Reihe. Band XXXIII. 1934.

HEILAND, C. A. Directions for the Use of the Askania Torsion Balance. 1933.

HENNEY, KEITH. Principles of Radio. Second edition. 1934.

HOLMES, HARRY N. Introductory Colloid Chemistry. 1934.

HOLMES, HARRY N. Laboratory Manual of Colloid Chemistry. Third edition, rewritten and reset. 1934.

JIPP, AUGUST. Moderne Telegraphie. Die Fernschreibetechnik mit dazugehörigen Leitungs- und Nebentechnik. 1934.

JONES, WILLIAM R. Tinfields of the World. 1925.

LEHR, ERNST. Schwingungstechnik. Ein Handbuch für Ingenieure. Zweiter Band: Schwingungen eingliedriger Systeme mit stetiger Energiezufuhr. 1934.

MARTIN, CHARLES R. A. Practical Food Inspection. Volumes 1–2. 1932–1933.

MEINESZ, F. A. VENING. Theory and Practice of Pendulum Observations at Sea. Publication of The Netherlands Geodetic Commission. 1929.

MONYPENNY, J. H. G. Stainless Iron and Steel. Second and revised edition. 1931.

MORECROFT, JOHN H. Elements of Radio Communication. Second edition, revised, enlarged, and entirely reset. 1934.

NIKURADSE, A. Das flüssige Dielektrikum. (Isolierende Flüssigkeiten.) 1934.

OSWALD, JOHN CLYDE. Benjamin Franklin in Oil and Bronze. 1926.

PRANDTL, L., AND O. G. TIETJENS. Applied Hydro- and Aeromechanics. Based on Lectures of L. Prandtl by O. G. Tietjens. Translated by J. P. Den Hartog. First edition. 1934.

PRANDTL, L., AND O. G. TIETJENS. Fundamentals of Hydro- and Aeromechanics Based on Lectures of L. Prandtl by O. G. Tietjens. Translated by L. Rosenhead. First edition. 1934.

RABONE, PHILIP. Flotation Plant Practice. 1932.

ROTHE, R., F. OLLENDORFF, AND K. POHLHAUSEN. Theory of Functions as Applied to Engineering Problems. Authorized translation by Alfred Herzenberg. 1933.

STOUGHTON, BRADLEY. The Metallurgy of Iron and Steel. Fourth edition. 1934.

THALAU, K., AND A. TEICHMANN. Aufgaben aus der Flugzeugstatik. Im Auftrage der Deutschen Versuchsanstalt für Luftfahrt E. V. Berlin-Adlershof. 1933.

THORNE, W. E. Testing and Estimating Alluvials for Gold, Platinum, Diamonds, or Tin. 1926.

TIMOSHENKO, S. Theory of Elasticity. First edition. 1934.

TONGUE, HAROLD. The Design and Construction of High Pressure Chemical Plant. 1934.

Welding Encyclopedia. A Practical Reference Book on Autogenous Welding. Eighth edition. 1932.

WORDEN, EDWARD CHAUNCEY. Chemical Patent Index. Volumes 3–5. 1933–1934.

ZEERLEDER, ALFRED VON. Technologie des Aluminiums und seiner Leichtlegierungen. 1934.

BOOK REVIEWS.

PHYSICAL CONSTANTS, SELECTED FOR STUDENTS. By W. H. J. Childs, Ph.D., The Davy-Faraday Research Laboratory, The Royal Institution. Methuen's Monographs on Physical Subjects. 77 pages, 10.8 × 17.1 cm. E. P. Dutton & Co., Inc. New York: Methuen & Co., Ltd., London, 1934. Price $1.20.

The theory underlying this little book is stated by the author as follows: " . . . The constants which are in everyday use are so limited in number that they could be collected into quite a small volume. The ideal book would be small and

light, to go easily into the pocket; the constants would be given with the proper number of significant figures, and would be the most recent determinations."

The material given is grouped under the usual divisions of Physics, such as Light. The opening section on Fundamental Units is by all odds the weakest and should be strengthened in future issues in the interests both of accuracy and of completeness of definition. For example (p. 2), the micromicron symbol $\mu\mu$ is given for the millimicron $m\mu = 10^{-6}$ mm. It is hard to reconcile (p. 3) angular velocity in the general terms T^{-1} when linear velocity has just been given in terms LT^{-1}; similar remarks apply to linear and angular accelerations. To define specific gravity (p. 4) without reference to temperature is inadequate.

It is noted that the International Joule is given as 1.00041 absolute Joule versus the value 1.00032 of International Critical Tables. No references to sources of values cited are volunteered except in general terms, hence in this and other cases one is left without a basis for decision and must resolve questions in favor of standard tables. The small calorie is not so designated but is capitalized and defined apparently without the consciousness that the biologist usually and the chemist frequently require a unit 1000 times greater although called by the same name.

Otherwise the book accomplishes the author's purpose acceptably. Fourteen pages of mathematical tables are included, giving four-place logarithms, antilogarithms, trigonometric functions, reciprocals and squares.

LESLIE R. BACON.

LE MYSTERE ET LE PARADOXE DU VOL ANIMAL, par le Docteur Emile Batault, 234 pages, plates, illustrations, 16.5 × 25 cms. Paris, Gauthier-Villars et Cie, 1933.

The secret of flight still continues to puzzle man. One might say the birds have it, so, for that matter, do the bats and mosquitoes. Man has solved a part of it. Some months ago I had occasion to peer down onto the roofs of what were once the very tall buildings of New York. Far below me, in fact, very far below the corona of the Empire State Building, the pigeons wheeled and circled and wheeled again, until I grew dizzy. They seemed tireless in their tilting rounds, completing as many as eighty cycles before they came to rest. I was watching the labor of true flying.

Dr. Batault has been caught on the same wheel and instead of being diverted by the sights and sounds of New York from the tower of the Empire State Building, he has devoted himself to the study of the problem of how birds fly. He reviews the theories that have been advanced, starting with the intrepid Leonardo da Vinci, re-airing the thought of the early workers and ending with the interesting motion pictures of a pigeon in flight made by M. Pierre Nogues. The pictures of successive moments while the bird is on the wing are excellent and are shown in full in accordian cut at the back of the book.

Of even more interest is the chapter that describes the anatomy of wings. The physiology and development of muscular energy are discussed in detail, one curious phase of which is the air filled sacks and the aerated bones of birds. In chapter IV there is considerable study made of M. Guyou's experiments in falling cats. On page 71 (Fig. 9) puss is shown starting her down-fall on her back, tail in and front paws working. By a clever twisting on her axis she reaches the ground

feet down and tail up. The drawings in sequence from 1 to 15 are very entertaining. It is the kind of experiment that any doubtful reader can try on the family cat. The odd thing is that it always works.

> "Nous avons appris qu'un animal qu'on laisse tomber dans l'air peut prendre appui, dans certaines conditions, sur l'inertie d'un partie de sa masse, soit en repos, soit en mouvement relatif."

The first part of the book concludes after a pretty close investigation of the physics of flight, the mechanism of wing stroke and other germane considerations. The second part deals with soaring which in these regions is so superbly done, on a summer day of rising air columns, by the turkey buzzard. As man is edging his way into this kind of flight, commonly known as gliding, it is in some ways the most repaying section of Dr. Batault's book. The mathematical relations expressed in chapter IX may describe the currents that support gliding flight, but the results are even more evident when one follows, as I did last summer, a sextet of turkey vultures as they glide in mighty curves over the brown fields of Harford County, Maryland. However, it is well to brush up on the supporting mathematics especially if one is ambitious to follow after in a private glider.

The third part of the work covers vertebrates other than birds and in chapter XIII the flight of insects which may be the way into a more winged life for man. Already structures of definite departure, from the fixed planes of the first vessels, are sustaining loads. Our explorations with insect-like wings has hardly begun.

Aside from technical investigation this book of Dr. Batault's provokes serious thought even in the mind of the arm-chair aviator. We have these glorious exhibitions of swift and beautiful flight to tease us to do likewise or at least to probe into the secret of how it is done. Dr. Emile Batault takes us definite steps along this way. Last summer, long before this book had fallen into my hand, I watched the swallows play with curves that could be described conservatively as expressions of music. They would glide through the air, skim the surface of a pond, and recover their flight with astounding grace and dexterity. The second paragraph of the preface brought their exhibition back most vividly to my mind.

> "D'autre part, l'observation des gracieuses évolutions des hirondelles, l'aisance et la rapidité de leurs movements—car le vol est bien, comme l'a dit Pettigrew, la poésie du movement—semblent contraires à toute idée d'effort excessif et épuisant, nécessité par ce genre de locomotion."

The book is well put together. Of course a paper back—I prefer them—pages to cut, but with simple and clearly designed illustrations worthy of the best French tradition.

H. W. ELKINTON.

PUBLICATIONS RECEIVED.

Scientific Organizations in Seventeenth Century France (1620–1680), by Harcourt Brown, 306 pages, 14.5 × 21 cms. Baltimore, The Williams & Wilkins Company, 1934. Price $3.00.

The Mysteries of the Atom, by H. A. Wilson, 145 pages, illustrations, 15.5 × 23.5 cms. New York, D. Van Nostrand Company, 1934. Price $2.50.

The Design and Use of Instruments and Accurate Mechanism, by T. N. Whitehead, 283 pages, plates, illustrations, 15 × 22.5 cms. New York, The Macmillan Company, 1934. Price $3.50.

The Story of Energy, by Morton Mott-Smith, 305 pages, 13 × 19 cms. New York and London, D. Appleton-Century Co., 1934. Price $2.00.

Machines automatiques mecaniques et electriques, par P. Maurer, 185 pages, 11.5 × 17.5 cms. Paris, Librairie Armand Colin, 1934.

Tables of Integrals and Other Mathematical Data, by Herbert Bristol Dwight, 222 pages, tables, 14.5 × 22 cms. New York, The Macmillan Company, 1934. Price $1.50.

Practical Forms in Exposition, by Harlow C. Richardson, Luther N. Becklund, Ledru O. Guthrie, Clifford I. Haga, 423 pages, 16 × 24 cms. New York, The Macmillan Company, 1934. Price $2.00.

Technics and Civilization, by Lewis Mumford, 495 pages, plates, 16 × 24 cms. New York, Harcourt, Brace & Company, 1934.

Achema Jahrbuch, Jahrgang 1931–1934, Berichte über Stand und Entwicklung des Chemischen Apparatewesens, variously paged, 15 × 21 cms. Hannover, Deutsche Gesellschaft für Chemisches Apparatewesen, 1934.

Canada, Dominion Bureau of Statistics, Report on the Fur Farms of Canada, 1931 and 1932, 203 pages, tables, illustrations, 16.5 × 25 cms. Ottawa, King's Printer, 1934. Price thirty-five cents.

Bell Telephone Laboratories, Monograph, B-772, Determination of the Direction of Arrival of Short Radio Waves, by H. T. Friis, C. B. Feldman and W. M. Sharpless, 32 pages, illustrations, 15 × 23 cms. B-774, Sound Film Printing-II, by J. Crabtree, 17 pages, illustrations, 15 × 23 cms. B-777, The Shot Effect and Electrical Breakdown in Insulators, by F. E. Haworth and R. M. Bozorth, 5 pages, illustrations, 15 × 23 cms. B-779, Iodine Value of Rubber and Gutta-Percha Hydrocarbons, by A. R. Kemp and G. S. Mueller, 11 pages, tables, illustrations, 15 × 23 cms. B-780, A Compensated Thermionic Electrometer, by K. G. Compton and H. E. Haring, 12 pages, illustrations, 15 × 23 cms. New York, Bell Telephone Laboratories, 1934.

National Advisory Committee for Aeronautics, Technical Notes No. 495, Effect of the Surface Condition of a Wing on the Aerodynamic Characteristics of an Airplane, by S. J. DeFrance, 3 pages, illustrations, 20 × 26 cms. Washington, Committee, 1934. No. 496, A Preliminary Motion-Picture Study of Combustion in a Compression-Ignition Engine, by E. C. Buckley and C. D. Waldron, 8 pages, illustrations, 20 × 26 cms. Washington, Committee, 1934. No. 497, Full-Scale Drag Tests of Landing Lamps, by C. H. Dearborn, 5 pages, tables, illustrations, 20 × 26 cms. Washington, Committee, 1934.

CURRENT TOPICS.

Pepping Up Sewage Gas.—An interesting report was submitted by R. E. HUSSEY, S. B. ROW AND W. W. ALLISON at the March Meeting of the American Chemical Society. They found that with proper temperature control the amount of gas which can be produced at the V. P. I.—Blackburg sewage disposal works is more than sufficient to supply the college demand. Should the supply fall off for some reason the volume can be increased by the addition of waste paper, extracted leaf waste or peanut hulls. Of these cellulosic materials, waste paper gives the greatest increase in methane while peanut hulls produces the least.

C.

Banishing the Locomotive Plume.—The *White Metal News Letter* announces that no longer will the locomotives of the Canadian Pacific Railway show "the white feather," as that wisp of steam is called by railroad men and which may be seen constantly escaping from the top of many engines. This symbol of power, accorded a certain degree of glamour by the more romantic minds, is looked upon as merely an unnecessary waste by the operators of the road. The blame for this trickle of steam is placed upon the wearing down of the whistle valve seat. Now the efficiency engineers are having the old type of seats replaced by monel metal so there will be no waste of steam between toots.

C.

Intimate Information About Lightning.—(*Science Service.*) Not so long ago a review of "Atmospheric Electricity" by B. F. J. SHONLAND appeared in this JOURNAL. Now the author, Cape Town University, in collaboration with H. COLLINS of the Victoria Falls and Transvaal Power Company, has reported some facts about lightning hitherto apparently unknown. By means of two lens, each making 1500 revolutions per minute, the experimenters could find not only the duration of the discharge, which way it was going and how fast, but also how long the luminosity persisted after the discharge had ceased, and other details.

Almost always they found that the main flash was preceded by a faint "leader." This traveled downward from the negatively charged cloud to the positively charged earth. As soon as it struck the earth, the main flash started upward from the same spot, and

followed exactly the same path that the leader had taken, to the cloud.

The leaders were invariably thin, of uniform width, and unbranched. Their speeds ranged from 810 to 19,900 miles per second and averaged 5150 miles. The length of the strokes observed varied from 1.6 to 4.7 miles. The longest time occuped by a leader stroke was 1670 millionths of a second for a 4.7 mile stroke.

The main discharge is entirely different in character. It is thicker and brighter, and the thickness diminishes upward. Also it travels faster. The speeds range from 14,900 to 68,400 miles per second, the average being 28,500 or about 15 per cent. of the speed of light. Often the main upward discharges were branched—but they branched downward. After each branch the main stem thinned but did not pause in its upward motion.

The time required for the main discharge to reach the cloud varied from 44 to 65 micro-seconds. The bright luminosity at the base lasted from 12 to 164 micro-seconds. A faint luminosity, however, lasted much longer, sometimes as much as 1/50th of a second, as though the path had been heated and continued to glow. In conformity with the theory proposed by Dr. N. E. Dorsey in 1926, the authors believe that the leader consists of an "electron avalanche" which goes ahead and ionizes the air, thus preparing a conducting path for the main discharge that follows.

C.

Moths Defy Cedar.—(U. S. D. A. Clip Sheet No. 824.) Cedarized containers do not stop clothes moths.—Alas, for some of us, this information arrives too late. We also, through a series of inadvertently conducted field tests, have discovered that cedar-lined closets and boxes do not in themselves a moth-free sanctuary make. The specialists of the Department of Agriculture do not believe that cedar-lined containers, or the odor of cedar for that matter, can be depended on for moth protection unless the articles in them are sprinkled plentifully with flake naphthalene or paradichlorobenzene crystals and the cracks about the doors of the closets and the lids of the boxes carefully sealed with adhesive tape.

C.

The Nation-Wide Residential Survey.—Members of communities "bursting with civic pride," will have an opportunity to discover whether they do so justifiably. The Bureau of Foreign and Domestic Commerce has been conducting a Real Property Inventory financed with funds from the Civil Works Administration. This

survey includes more than 60 cities representing every state. So far, only preliminary statistics for Casper, Wyoming, have been released. Out of about 4270 structures surveyed in Casper, 2783 were found to be in need of repairs of some kind, while 262 were listed as "unfit for human habitation." The structures surveyed contained a total of 5600 residential units, while 400 of those habitable were unoccupied giving Casper a vacancy of about 7 per cent.

Over 75 per cent. of the residences were constructed between 1915 and 1925 while only 48 houses have been erected since the end of 1929. Over 82 per cent. of the buildings are of frame construction and almost half the homes are without basements. About one-third of the dwelling units were owned by their occupants and 60 per cent. of these had no mortgages or liens on them. It is interesting to find that less than 2 per cent. of the living quarters were classified as over crowded while about 80 per cent. were considered to be adequate.

About 12 per cent. of the residential units were without running water—hot or cold—while 1410 units had no private indoor water closets, and 1721 had no tubs or showers, over 25 and 30 per cent. respectively. More than half the residences were heated by gas, and only 31 dwellings had no heating apparatus whatsoever.

C.

And Now Coffee Flakes.—In the Twenty-First Annual Report of the Mellon Institute, the Director, E. R. Weidlein, describes briefly the recently completed fellowship developmental work upon "Flaked Coffee, a New Research Creation." The aim of this investigation begun in 1929 was twofold, namely to secure a better degree of preservation of roasted coffee and also if possible to increase the value of the coffee to the purchaser.

Green coffee may be kept for long periods of time if protected from mold and bacterial growth, but roasted coffee immediately begins a gradual deterioration that is more rapid when it is ground. Coffee aroma is a complex mixture of volatile compounds formed by pyrolysis (disintegration by heat) of the components of the green coffee bean. The soluble non-volatile principles of the bean likewise undergo pyrolysis, resulting in the production of caramel-like substances that give body to the brew prepared from the roasted coffee. Coffee also contains a fatty oil that undergoes some alterations during roasting. Coffee becomes stale because of the volatilization of aroma, oxidation of aroma, and oxidation or rancidity of the coffee oil.

Roasting of the coffee produces a considerable quantity of gas in which carbon dioxide predominates. A large proportion of this gas is retained by the roasted bean and after grinding slowly escapes, carrying along with it much of the aroma. When attempts are made to preserve the freshly roasted coffee by immediate hermetic sealing, the accumulating gas produces such a pressure as to rupture the container unless one of special strength is provided. If, on the other hand, the container is vacuumized, the occluded gas is by no means completely removed during the operation. This residual gas gradually builds up a pressure in the container, and upon opening rushes out carrying the aroma along with it.

This fellowship has found that the application of high pressure to ground freshly roasted coffee will expel about 90 per cent. of the occluded gas, with practically no loss of aroma. Such pressure is conveniently applied by a roller mill which converts the coffee particles into thin, flat, coherent flakes, averaging about 0.06 inch in diameter and about 0.003 inch in thickness. Coffee in this form may be hermetically sealed in containers in an atmosphere of carbon dioxide and remain fresh for at least a period of two years.

Because of the accessibility of the soluble constituents in these flakes, extraction is not only much more rapid but is also more uniform and much more complete. Flaked coffee yields during brewing operations approximately 50 per cent. more extractive than is obtained from the customary drip grind and from 75 to 100 per cent. more than is had from the ordinary percolator grind. Flaked coffee yields its extractives so readily that a good beverage may be prepared by steeping, as is done with tea.

C.

Hard-Finished Protected Metal.—Some time ago Current Topics made mention of a new structural material, Robertson Bonded Metal. Examples are the bonding of a fiber or hair-felt sheet to one of steel, using readily fusible metallic alloys and the superimposing of wood veneer surfaces upon drawn steel shapes by means of resin adhesive. However, the sponsors did not stop there. The Director of Mellon Institute, in his Twenty-First Annual Report describes how the fellowship has extended its activities to other methods of protecting metal structural units. This work has resulted in the development of a Hard-Finished Robertson Protected Metal. The material consists of a novel cement outer coating upon an asphalt-asbestos protected steel core. Made principally in the sheet form, they are erected in the same manner as corrugated steel sheets. The cement coating permits combinations of the permanent earth oxide colors such as buff, green, red and stone-gray.

Such a coating is naturally of a refractory nature and these protected metal sheets exhibit a remarkable resistance to fire. Used as roofing and siding, such sheets are found to provide a cooler covering for buildings exposed to the sun and, conversely, a warmer protection in cold weather.

C.

The Science of Manicuring.—Announcement has been made that a Fellowship on Cosmetics, located at one of the country's leading Institutes of Industrial Research, is mainly conducting research on problems in the chemistry and pharmacology of manicuring. Many will await with interest any report of findings which may be forthcoming.

C.

THE FRANKLIN INSTITUTE

OFFICERS FOR 1934

President	NATHAN HAYWARD
Vice-presidents	HENRY HOWSON C. C. TUTWILER WALTON FORSTALL W. CHATTIN WETHERILL
Secretary	HOWARD MCCLENAHAN
Assistant Secretary and Librarian	ALFRED RIGLING
Treasurer	BENJAMIN FRANKLIN
Assistant Treasurer	MARSHALL S. MORGAN
Controller	WILLIAM F. JACKSON, JR.

Board of Managers

HENRY BUTLER ALLEN
GEORGE H. BENZON, JR.
EDWARD G. BUDD
FRANCIS T. CHAMBERS
G. H. CLAMER
WALTON CLARK
CHARLES H. EWING
SAMUEL S. FELS
WILFRED W. FRY
C. D. GALLOWAY
ARTHUR W. GOODSPEED
CLARENCE A. HALL
GEORGE A. HOADLEY
A. ATWATER KENT
L. H. KINNARD
ROBERT W. LESLEY
HORACE P. LIVERSIDGE
MALCOLM LLOYD, JR.
CHARLES PENROSE
GEORGE WHARTON PEPPER
JAMES S. ROGERS
GEORGE D. ROSENGARTEN
SAMUEL M. VAUCLAIN

INDEX TO VOL. 217.

Absorption measurements of the cosmic radiation (Johnson), 167
Acoustics architectural, Recent developments in (Sabine), 443
Aerial navigation. Celebration commemorating the thirtieth anniversary of the flight of the Wright brothers at Kitty Hawk, N. C. (Franklin Institute), 237
Aerial navigation. Superaerodynamics (Zahm), 153
Air, clean, an achievable asset (Meller), 709
Architectural acoustics. Recent developments in (Sabine), 443
Atmospheric dust recorder (Hazard), 571
Baker, Edward B.: The rôle of dissolved gases in determining the behavior of mineral insulating oils, 373
Bay of Fundy tides. The probable effect of tidal development on (Hachey), 747
Beta-particles, swift. Ionization by (Locher), 39
Bismuth. The heat dissociation of (Ko), 173
Book Reviews:
Batault, E.: "Le Mystere et le Paradoxe du Vol Animal," 767
Bewley, L. V.: Traveling waves on transmission systems, 147
Chemical Engineering Catalog, 1933, 148
Chemical Patents Index, vols. 3, 4, 5, 653
Childs, W. H. J.: Physical Constants, Selected for Students, 766
Daynes, H. A.: Gas analysis, 652
Franklin, P.: Differential equations for electrical engineers, 394
Hatfield, H. S.: The inventor and his world, 263
Heidel, W. A.: The heroic age, 396
Hou, Te-P.: Manufacture of soda, 395
Jahnke, E. & F. Emde: Funktionentafeln, 393
Koller, L. R.: The physics of electron tubes, 393
Liddell, D. M. & G. E. Doan: The principles of metallurgy, 650
Littleton, J. T. & G. W. Morey: The electrical properties of glass, 146
Mott-Smith, M.: This mechanical world, 539
National Advisory Committee for Aeronautics, Reports: No. 460, 149; No. 463, 535; No. 466, 536; No. 467, 536; No. 470, 149; No. 472, 537; No. 473, 537; No. 474, 651; No. 475, 538; No. 476, 538
National Research Council, Bulletin No. 90, Physics of the earth, part VI, 397
Philosophy of Science, 147
Schonland, B. F. J.: Atmospheric electricity, 264
Thum, E. E.: The book of the stainless steels, 398
Bush, V.: Structural analysis by electric circuit analogies, 289
Carbon microphone (Goucher), 407
Cellulose. Before papyrus . . . beyond rayon (Esselen), 273
Chicken protein. Biochemical studies of (Hepburn, Sohn & Devlin), 213
Cosmic radiation. Absorption measurements of the (Johnson), 167
Cosmic ray counters. Vacuum tube characterisics in relation to the

selection of coincident pulses from (Fussell & Johnson), 517
Cosmic ray deflection experiments. Analysis of (Danforth), 331
Cosmic-ray particles. Ionization by (Locher), 39
Cosmic rays in the atmosphere. Low energy, Experiments on the distribution of (Danforth & Lipman), 73
Cosmic rays, secondary. Measurement of the ionization by (Swann), 79
Current topics: 38, 72, 102, 112, 172, 200, 222, 226, 236, 266, 288, 330, 346, 352, 400, 516, 530, 541, 570, 616, 626, 655, 708, 746, 770
Curtiss magnetic deflection experiments (Danforth), 331
Danforth, W. E.: Analysis of cosmic ray deflection experiments, 331
Danforth, W. E. & M. R. Lipman: Experiments on the distribution of low-energy cosmic rays in the atmosphere, 73
Devlin, Laurence Patrick, Joseph Samuel Hepburn & Keum Sung Sohn: Biochemical studies of soy bean milk and chicken protein, 213
Dust recorder. Atmospheric (Hazard), 571
Electric circuit analogies. Structural analysis by (Bush), 289
Esselen, Gustavus J.: Before papyrus . . . beyond rayon, 273
Ferris, S. W.: Petroleum refining by means of selective solvents, 591
Flow of fluids. The determination of the direction and velocity of (Marks), 201
Fluids, flow of, The determination of the direction and velocity of (Marks), 201
Franklin Institute:
Bartol Research Foundation.
Communications, No. 81: Experiments on the distribution of low-energy cosmic rays in the atmosphere (Danforth & Lipman), 73
Communication, No. 82: Measurement of the ionization per centimeter of path by individual secondary cosmic rays (Swann), 79
Communication, No. 83: The ionization by cosmic-ray particles and swift beta-particles (Locher), 39
Communication, No. 84: The representation of radiation reaction in wave mechanics (Swann), 59
Communication, No. 85: Analysis of cosmic ray deflection experiments (Danforth), 331
Communication, No. 86: Vacuum tube characteristics in relation to the selection of coincident pulses from cosmic ray counters (Fussell & Johnson), 517
Notes: 113,
Celebration commemorating the thirtieth anniversary of the flight of the Wright brothers at Kitty Hawk, N. C., and the dedication of the aviation section of the museum, 237
Historic Franklin Institute, 119
Library, Formal opening and dedication, 627
Library Notes: 260, 391, 534, 648, 764
Membership notes: 145, 259, 388, 532, 646, 763
Museum, Aviation section, Dedication, 237
Science and the Arts Committee, Abstract of proceedings: December 13, 1933, 144; January 10, 1934, 259; February 14, 1934, 387; March 14; 1934, 531; April 11, 1934, 646; May 9, 1934, 762
Stated meeting, proceedings: December 20, 1933, 143; January 17,

1934, 257; February 21, 1934, 385; March 21, 1934, 531; April 18, 1934, 645; May 16, 1934, 761

Fussell, Lewis Jr. and Thomas H. Johnson: Vacuum tube characteristics in relation to the selection of coincident pulses from cosmic ray counters, 517

Gases, dissolved, The role of, in determing the behavior of mineral insulating oils (Baker), 373

Goodhue, W. M.: Subharmonic frequencies produced in non-linear systems, 87

Goucher, F. S.: The carbon microphone, an account of some researches bearing on its action, 407

Gundelfinger, Alan M.: Spectrophotometric determination of tone intensification in color motion picture film, 505

Hachey, H. B.: The probable effect of tidal development on Bay of Fundy tides, 747

Hazard, Willis G.: An atmospheric dust recorder, 571

Heat of dissociation of Bi_2 (Ko), 173

Hepburn, Joseph Samuel, Keum Sung Sohn & Laurence Patrick Devlin: Biochemical studies of soy bean milk and chicken protein, 213

Inglis, David Rittenhouse: On the hypothesis of a critical field in superconductivity, 227

Insulting oils, mineral, The role of dissolved gases in determining the behavior of (Baker), 373

Ionization, Measurement of, per centimeter of path by individual secondary cosmic rays (Swann), 79

Johnson, Thomas H.: Absorption measurements of the cosmic radiation, 167.

Johnson, Thomas H. & Lewis Fussell, Jr.: Vacuum tube characteristics in relation to the selection of coincident pulses from cosmic ray counters, 517

Ko, Cheng Chuan: The heat dissociation of Bi_2 determined by the method of molecular beams, 173

Langmuir, Irving: Thoriated tungsten filaments, 543

Lipman, M. R. & W. E. Danforth: Experiments on the distribution of low-energy cosmic rays in the atmosphere, 73

Locher, Gordon L.: The ionization by cosmic-ray particles and swift beta-particles, 39

Lucas, Francis F.: Late developments in microscopy, 661

Marks, Lionel S.: The determination of the direction and velocity of flow of fluids, 201

McGivern, J. G. & H. L. Supper: A membrane analogy supplementing photo-elasticity, 491

Meller, H. B.: Clean air, an achievable asset, 709

Membrane analogy supplementing photo-elasticity (McGivern & Supper), 491

Merrill, A. A.: The Michelson-Morley experiment, 223

Michelson-Morley experiment (Merrill), 223

Microphone carbon (Goucher), 407

Microscopy. Late developments in (Lucas), 661

Moore, W. H.: Simple ultra short wave wavemeters, 347

Motion picture film, color, Spectrophotometric determination of tone intensification in (Gundelfinger), 505

Mott-Smith magnetic deflection experiments (Danforth), 331

Non-linear systems. Subharmonic frequencies produced in (Goodhue), 87

Papyrus, before . . . beyond rayon (Esselen), 273

Particle size. The coefficient of resistance as a function of Reynolds number for solids of various shapes (Wadell), 459
Petroleum refining (Ferris), 591
Photo-elasticity. Membrane analogy supplementing (McGivern & Supper), 491
Publications received: 150, 264, 398, 540, 654, 768
Radiation reaction in wave mechanics. The representation of (Swann), 59
Rayon. Before papyrus . . . beyond, (Esselen), 273
Sabine, Paul E.: Recent developments in architectural acoustics, 443
Silverman, I. K.: On forced pseudo-harmonic vibrations, 743
Sohn, Keum Sung, Joseph Samuel Hepburn & Laurence Patrick Devlin: Biochemical studies of soy bean milk and chicken protein, 213
Solids of various shapes. The coefficient of resistance as a function of Reynolds number for (Wadell), 459
Soy bean milk. Biochemical studies of (Hepburn, Sohn & Devlin), 213
Spectrophotometric determination of tone intensification in motion picture film (Gundelfinger), 505
Strelzoff, J. A.: Some transmission line transients. Graphical evaluation by Fourier's series, 353
Structural analysis by electric circuit analogies (Bush), 289
Subharmonic frequencies produced in non-linear systems (Goodhue), 87
Superaerodynamics (Zahm), 153
Superconductivity. On the hypothesis of a critical field in (Inglis), 227
Supper, H. L. & J. G. McGivern: A membrane analogy supplementing photo-elasticity, 491
Swann, W. F. G.: Measurement of the ionization per centimeter of path by individual secondary cosmic rays, 79
Swann, W. F. G.: The representation of radiation reaction in wave mechanics, 59
Television (Zworykin), 1
Thoriated tungsten filaments (Langmuir), 543
Tidal development, The probable effect of on Bay of Fundy tides (Hachey), 747
Trajectory. A method of computing differential corrections for a (Wertheimer), 729
Transmission line transients (Strelzoff), 353
Tungsten filaments. Thoriated (Langmuir), 543
U. S. Bureau of Standards, Notes: 103, 229, 375, 525, 617, 757
Vacuum tube characteristics (Fussell & Johnson), 517
Vibrations, pseudo-harmonic, On forced (Silverman), 743
Wadell, Hakon: The coefficient of resistance as a function of Reynolds number for solids of various shapes, 459
Wave mechanics. Radiation reaction in, The representation of (Swann), 59
Wavemeters. Simple ultra short wave (Moore), 347
Wertheimer, Albert: A method of computing differential corrections for a trajectory, 729
Wright brothers flight. Celebration commemorating the thirtieth anniversary (Franklin Institute), 237
Zahm, A. F.: Superaerodynamics, 153
Zworykin, V. K.: Television, 1